DETERMINATION OF THE HEAT TREATMENT PARAMETERS ALLOWING TO OBTAIN A FERRITIC-BAINITIC-AUSTENITIC MICROSTRUCTURE IN THE STRUCTURAL STEEL

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Abstract

The phase transformations which occur in 38CrAlMo6-10 steel were analysed at various temperatures, particularly in the intercritical Ac_1-Ac_3 region, by means of computer simulations and by dilatometric tests. In the study, the effects of heat treatment conditions in the intercritical region on the martensitic and bainitic transformations and on the Ms temperature were investigated. On the basis of obtained results, the conditions for annealing in the intercritical region before isothermal quenching were proposed. Such treatment led to the formation of the multiphase microstructure, which consisted of carbide-free bainite with austenite in the ferritic matrix in 38CrAlMo6-10 steel. The obtained results indicate that the computer simulations supported by dilatometric measurements of phase transformations may are an effective method for planning the heat treatment in the intercritical region.

Keywords: multiphase steels, phase transformation simulations, dilatometric tests, phase transformation in Fe alloys, heat treatment

1. INTRODUCTION

The intercritical annealing of structural steels is commonly used to obtain a dual phase or a complex phase microstructures [1]. However, the influence of the intercritical annealing parameters on bainitic transformation occurring during isothermal annealing is not well understood. The isothermal annealing process is commonly used for obtaining a bainitic structure. The proper selection of isothermal annealing parameters enables to control the mechanical properties of medium- and high-carbon steels. In particular, in steels containing the increased amount of Silicon or Aluminium it allows to obtain a nanobainitic microstructure during isothermal quenching [2]. This microstructure is composed of carbide-free plates of bainite separated from each other with the austenite layers. The nanobainitic steels exhibit higher ductility and higher crack resistance (fracture toughness) in comparison with the lower and higher bainite [3]. A carbide-free bainitic microstructure with retained austenite is difficult or even impossible to form in steels with low carbon content (below 0.4%). It is due to the insufficient carbon concentration in austenite. However, carbon content in austenite for such steels maybe increased through incomplete austenitization, i.e. annealing in the area of coexistence of ferritic and austenitic phases (α+γ).

In the hypoeutectoid steels, annealing in the temperature range between Ac_1 and Ac_3 enables to achieve equilibrium between ferrite and austenite. A change in the annealing temperature in the α+γ region affects both the volume fraction of austenite in relation to ferrite and the carbon concentration in austenite [4]. Hence, the structure obtained after annealing in various temperatures in the coexistence region of α and γ phases, followed by isothermal quenching, would differ in terms of bainite and ferrite ratio. Moreover, the bainitic structure would be changed due to different initial carbon concentrations in austenite. Carbon enrichment of austenite in the α and γ regions should enable to obtain a stable microstructure consisting of carbide-free bainite plates separated from each other with the retained austenite layers. Such microstructure should enhance the mechanical properties of steel, especially its ductility and impact strength, while maintaining its high tensile strength parameters.

The aim of the study was to determine, by computer simulations and dilatometric tests, the heat treatment parameters which allow obtaining a carbide-free bainitic microstructure with the retained austenite in the ferritic matrix of 38CrAlMo6-10 steel.

2. EXPERIMENTAL

The analysis of the phase transformation simulation was conducted with the use of JMatPro computer program [5]. Dilatometric tests were carried out with the use of Baehr DIL805L quenching dilatometer. It was essential to determine the annealing conditions in the region of coexistence of α+γ phases and their influence on the martensitic and bainitic transformation, in particular the Ms temperature and the times of the start and the end of bainitic transformation. For this purpose, the dilatometric measurements were performed during continuous quenching and quenching with isothermal annealing after applying various conditions of annealing in the intercritical region.

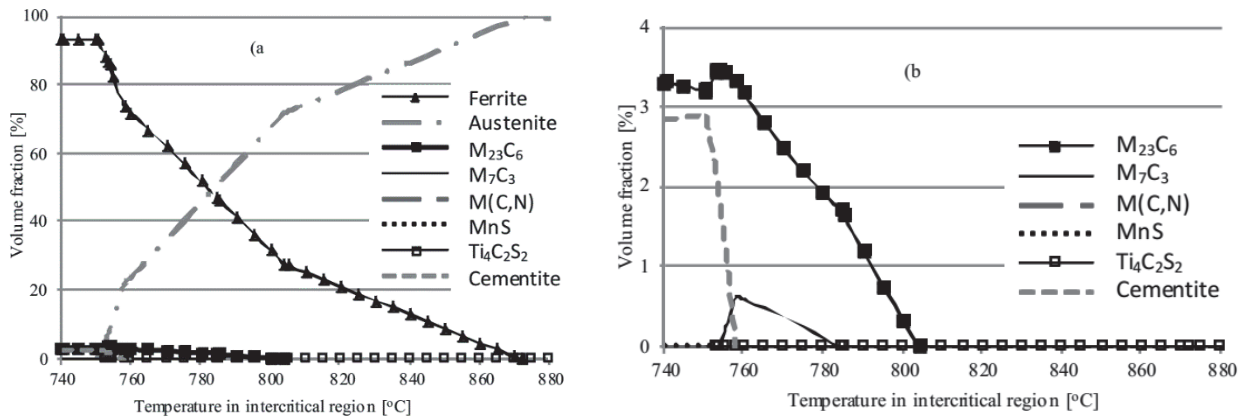
In this study, 38CrAlMo6-10 structural steel designated for nitriding [6] was used (**Table 1**). It contains the increased amount of Al which hinders the cementite precipitation.

Table 1 Chemical composition of 38CrAlMo6-10 steel [wt. %]

C	Mn	Si	Cr	Ni	Mo	Al	P	S	Cu	V
0.38	0.62	0.33	1.54	0.19	0.25	0.97	0.016	0.004	0.16	0.004

3. PHASE TRANSFORMATION SIMULATIONS OF 38CrAlMo6-10 STEEL

The stability range of α+γ phases for 38CrAlMo6-10 steel is within the temperature range between 750 °C and 872 °C (**Fig. 1a**). According to the simulation, both ferritic and austenitic phase have the same volume fraction (~48.5 %) in 783 °C temperature.



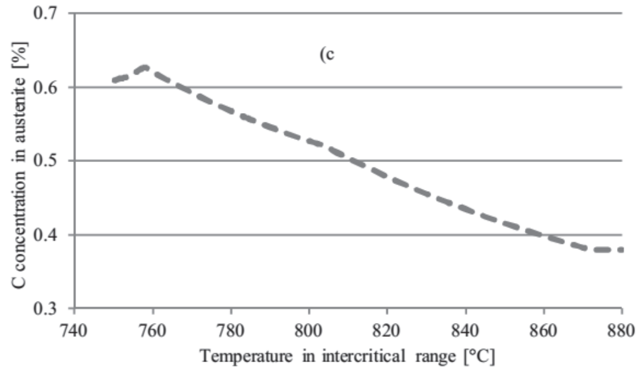


Fig.1 The results of JMatPro simulations for 38CrAlMo6-10 steel in the temperature range of α+γ coexistence (a-phase composition, b-carbide volume fraction, c- carbon concentration in austenite)

Carbon concentration in austenite for 38CrAlMo6-10 steel is the highest (0.63 %C) at the temperature of 758 °C at which the cementite totally dissolves (**Fig. 1c**).

M_7C_3 carbides dissolve completely in 785 °C, whereas $M_{23}C_6$ carbides dissolve in 804 °C (**Fig. 1b**). M(C,N) carbide appears in very small quantities for lower temperatures, while the sulphide (MnS) and carbon-sulphide $Ti_4C_2S_2$ occur in the whole intercritical region. The temperatures of the full carbides dissolution: $M_{23}C_6$ (804 °C) and M_7C_3 (785 °C) seem promising in terms of the multiphase structure formation because at these temperatures this steel contains a significant amount of austenite with high carbon concentration (72 %-0.52 %C and 52 %-0.56 %C respectively).

4. THE ANALYSIS OF THE RESULTS OF DILATOMETRIC TESTS

The simulations of phase transformations in 38CrAlMo6-10 steel enabled to select the temperatures of annealing in the intercritical region which were as follows: 785 °C and 800 °C. In both considered cases, carbon enrichment in austenite occurred. It was reflected by a decrease in the Ms temperature.

After the first half an hour, 95 % of the transformation takes place at 800 °C and 81% of the transformation takes place at 785 °C. Continuous decrease in the length of a sample, even after an hour annealing, indicates that the transformation, which occurs in the material, is not completed (**Fig. 2**).

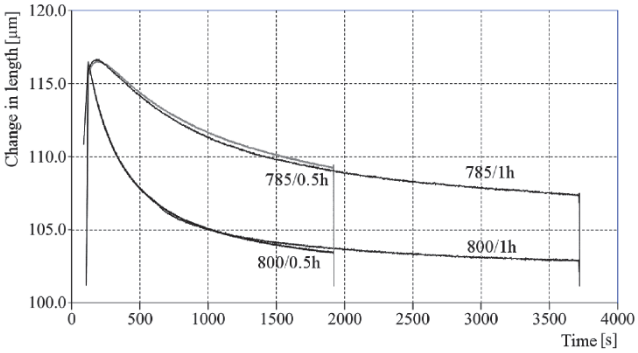


Fig. 2 Change in the length of a dilatometric sample of 38CrAlMo6-10 steel during the intercritical annealing

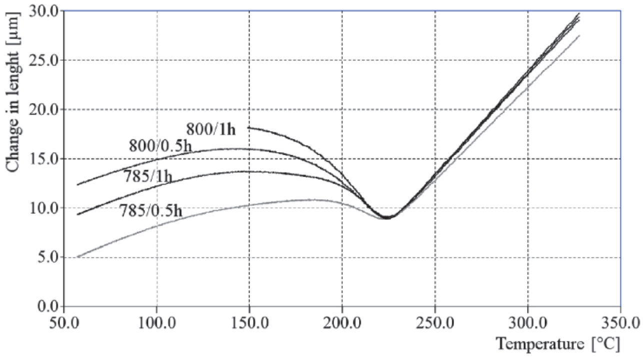


Fig. 3 The effect of the temperature and the time of annealing in the intercritical range on the increase in the sample length during the martensitic transformation

A decrease in the annealing temperature for 38CrAlMo6-10 in the intercritical range leads to a drop in the Ms temperature of about 20 °C. According to the computer simulations, this change in Ms temperature corresponds to the difference in the carbon concentration in austenite of about 0.03 % (**Table 2**). However, it is impossible to determine the effect of the annealing time in the intercritical region on the Ms temperature since the results of half an hour and an hour annealing are similar.

Table 2 The effect of the intercritical annealing time and temperature on the Ms temperature in 38CrAlMo6-10 steel

T [°C]	t [h]	Ms [°C]	Austenite volume friction by JMatPro [%]	Carbon concentration in the austenite in the intercritical region by JMatPro [%]
785	0.5	238	52	0.56
	1	234		
800	0.5	251	69	0.53
	1	257		

The increase in length of a sample during the martensitic transformation in the dual-phase steels depends on the proportion of austenite and ferrite. The greater austenite fraction (due to the higher temperature of intercritical annealing), the higher volume fraction of martensite is formed. In **Fig. 3** greater gain in length of the sample during a dilatometric test is seen.

5. ISOTHERMAL QUENCHING

According to the simulations (Chapter 3) and to the dilatometric tests (Chapter 4), two temperatures were chosen for the intercritical annealing in 38CrAlMo6-10 steel before undergoing isothermal quenching. They were as follows: annealing in the intercritical region at 785 °C for 0.5h which leads to 52 % of austenite being formed, whereas the annealing in the intercritical region at 800 °C for 0.5 h leads to 69 % of austenite.

Bainitic quenching at various temperatures of the isothermal stop was conducted for the aforementioned annealing conditions. The fragment of TTT diagram for bainitic transformation was determined according to the heat treatments results obtained from the dilatometric tests (**Fig. 4**).

The lack of transformation incubation time is characteristic for 38CrAlMo6-10 steel. It means that bainitic transformation begins right after cooling down to the isothermal stop temperature. Thus, the time, at which the transformation begins, has not been displayed on the diagram. The time needed to complete the bainitic transformation, for different temperatures of the isothermal annealing, is similar for both examined temperatures of the intercritical annealing.

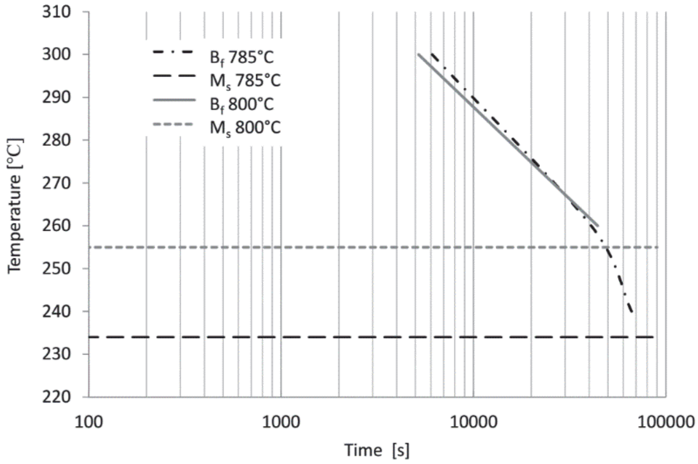


Fig. 4 The section of TTT diagram of 38CrAlMo6-10 steel after half an hour of annealing in the intercritical range at 785 °C and at 800°C.

CONCLUSIONS

- Specific conditions of the intercritical annealing before the isothermal quenching process may be determined according to the simulations and the dilatometric tests.
- The intercritical annealing time and temperature affect the parameters such as: the degree of martensitic and bainitic transformations, the Ms temperature, and the kinetics of bainitic transformation.
- The increase in the carbon concentration in austenite led to a decrease in the Ms temperature due to the lower temperature of the intercritical annealing.
- The time of the intercritical annealing has a significant influence on the degree of martensitic transformation, but only a slight influence on the Ms temperature.

ACKNOWLEDGEMENTS

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