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TRANSFORMATION KINETICS OF SELECTED STEEL GRADES AFTER PLASTIC DEFORMATION

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The aim of this article was to assess the impact of previous plastic deformation on the kinetics of transformations of four selected steels. The research was conducted with use of the universal plastometer GLEEBLE 3800, when Continuous Cooling Transformation (CCT) and Deformation Continuous Cooling Transformation (DCCT) diagrams of selected steels were constructed on the basis of dilatometric tests. The research confirmed that the strain accelerates the particularly the transformations controlled by diffusion. Bainitic transformation was accelerated in three of the four steels. In the case of martensitic transformation the effect of the previous deformation was relatively small, but with clearly discernible trend.

Key words: steel, plastic deformation, phase transformation, dilatometric tests, CCT and DCCT diagrams

INTRODUCTION

Thermo-mechanical treatment of steels is not possible without knowledge of the kinetics of phase transformations. It is for the modes of cooling most often described by the transformation diagrams of Time Temperature Transformation (TTT) or Continuous Cooling Transformation (CCT). Their validity is determined by the chemical composition and by conditions of austenitisation of the given steel. The kinetics of transformations is moreover influenced also by previous plastic deformation, as it was stated in many previous papers [1-5]. The effect of plastic deformation on the kinetics of transformation during continuous cooling is then illustrated by Deformation Continuous Cooling Transformation (DCCT) diagrams [1-5].

It is generally assumed that input strain accelerates particularly the transformations controlled by diffusion only (ferrite and pearlite). In the case of bainitic transformation the influence of the strain is ambiguous. In the case of martensitic transformation a slightly deaccelerating effect is assumed [1,3,6-8].

This paper is focused on research of the influence of strain on the kinetics of transformations during cooling of selected steels with a wide range of chemical composition. Dilatometric tests conducted on the universal plastometer Gleeble 3800, installed at the Regional Materials Science and Technology Centre (RMSTC), at the VŠB - Technical University of Ostrava (VŠB - TU Ostrava) were used for construction of the CCT and DCCT diagrams [5].

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EXPERIMENTAL PROCEDURE

Four steels were selected for the purposes of experiment, specifically: A - 20MnCrS5, B 32CrB4, C - 51CrV4 and D - IH class Rail Steel. Chemical composition of these steels in accordance with the standards is given in Table 1.

Two types of samples were manufactured from the selected steels. The first type of the samples were samples of special design with the diameter of 10 mm and total length of 84 mm with hollow head parts and reduced central part of the sample with the diameter of 5 mm and the length of 5 mm. For dilatometric tests with influence of strain cylindrical samples of the type SICO with the diameter of 10 mm and the length of the heated part of 10 mm were selected [5].

Table 1 **Chemical composition of selected steels / wt. % [9-12]**

Steel grade	A	B	C	D
C	0,17 -0,22	0,30 -0,34	0,47 -0,55	0,74 -0,84
Mn	1,10 -1,40	0,60 -0,90	0,70 -1,10	0,75 -1,25
Cr	1,00 -1,30	0,90 -1,20	0,90 -1,20	max. 0,30
Si	max. 0,40	max. 0,30	max. 0,40	0,10 -0,60
V	-	-	0,10 -0,25	max. 0,010
Ni	-	-	-	max. 0,25
Mo	-	-	-	max. 0,06
S	0,02 -0,04	max. 0,025	max. 0,035	max. 0,020
P	max. 0,035	max. 0,025	max. 0,025	max. 0,020
Norm	EN 10084-1998	EN 10263-4	EN 10083-3	-
	[9]	[10]	[11]	[12]

The samples were austenitised by electric resistance heating during 120 s at the temperatures of steels A, B, C = 850 °C, rail steel D = 860 °C. In the case of tests without previous deformation a cooling followed to the temperature of 25 °C at constant rates chosen in such a range, which enabled coverage of the whole spectre of running transformations. In the case of sample influenced by previous real compression strain of the magnitude of 0,35 and strain rate of 1 s^{-1}, the samples were cooled at constant rates only after the deformation itself.

All the tested samples were then subjected to metallographic analyses and measurements of hardness HV30.

DISCUSSION OF RESULTS

The CCT and DCCT diagrams were constructed on the basis of analysis of dilatometric curves during cooling conducted at selected cooling rates. These diagrams were then interlaid into one special comparative diagram, which enabled much easier evaluation of influence of the previous deformation on the kinetics of phase transformations for the given steel [5].

First of all the influence of deformation on the kinetics of phase transformations in the steel A – 20MnCrS5 was evaluated [9]. Special comparative diagram for this steel is shown in Figure 1.

It can be seen in Figure 1 that the input strain in the steel 20MnCrS5 significantly accelerates both ferritic and pearlitic transformation, which are fully controlled by diffusion [2], and also bainitic transformation. The curves of the relevant transformations are therefore shifted to the left towards shorter times. In the case of martensitic transformation the temperature of the start of this transformation was also slightly increased as a result of deformation, particularly in the cases of slower cooling rates.

The steel B - 32CrB4 [10] was the next tested steel. The comparative diagram for this steel is shown in Figure 2.

In this case too it was confirmed that previous deformation accelerated both the transformations controlled by diffusion (ferritic and pearlitic), but also the bainitic transformation – see Figure 2. In this case, however, the curve of the start of martensitic transformation was as a result of deformation shifted towards lower temperatures, which confirms the propositions that a dense dislocation network is created as a result of deformation, which hinders the progress of the phase interface, and in spite of large number of nuclei the portion of the new phase is usually smaller then in the case of transformation of non-deformed austenite, particularly in the case of higher cooling rates [3, 7].

This fact is confirmed also by the comparative diagram of the spring steel C – 51CrV4 [11], which is shown in Figure 3.

As it can be seen in Figure 3, in this case too the pearlitic transformation was accelerated.

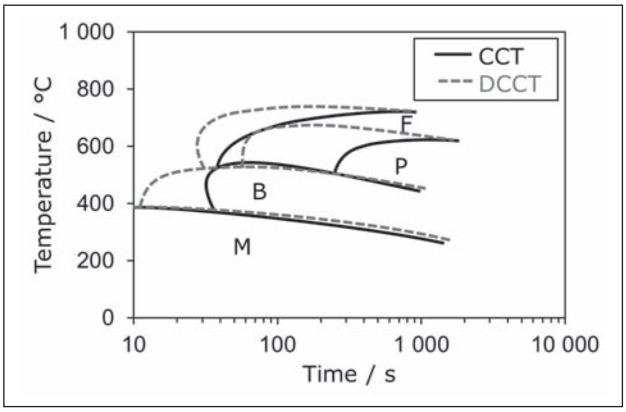

Figure 1 Effect of deformation in the CCT diagram for the steel A - 20MnCrS5

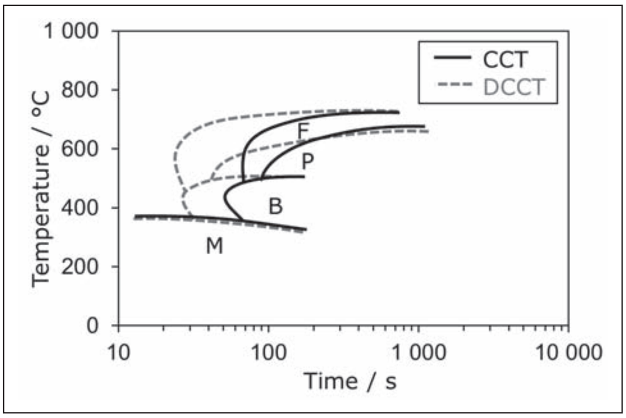

Figure 2 Effect of deformation in the CCT diagram for the steel B – 32CrB4

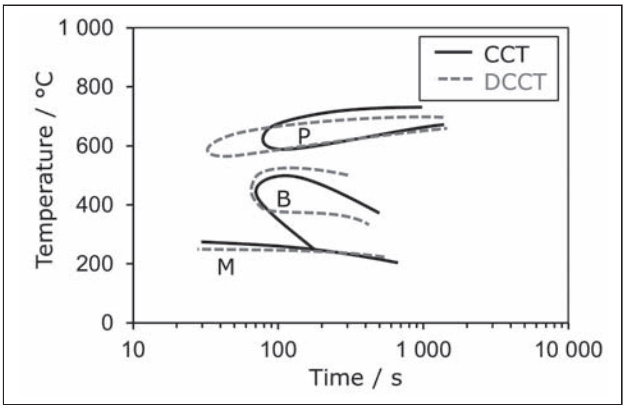

Figure 3 Effect of deformation in the CCT diagram for the steel C – 51CrV4

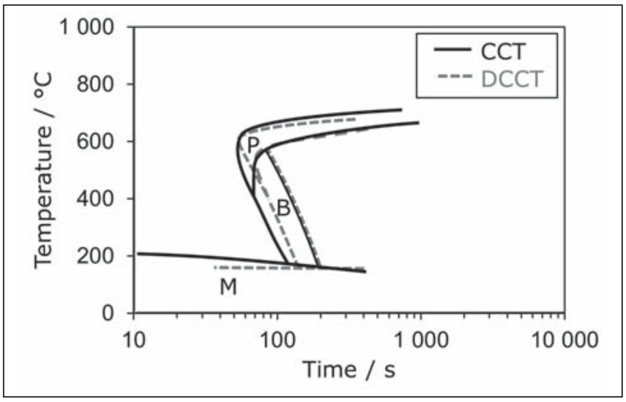

Figure 4 Effect of deformation in the CCT diagram for the steel D – IH class Rail Steel

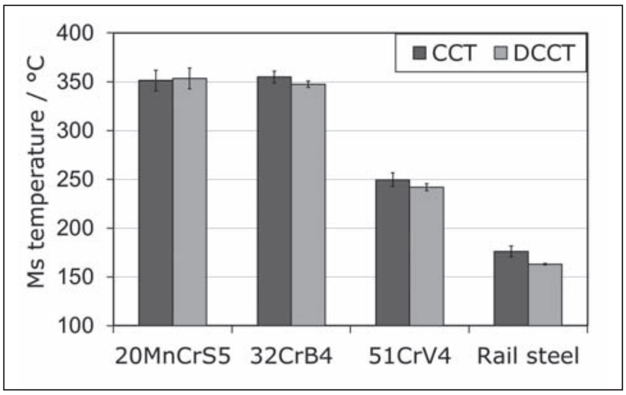

Figure 5 Effect of deformation on the martensite start temperature of selected steels

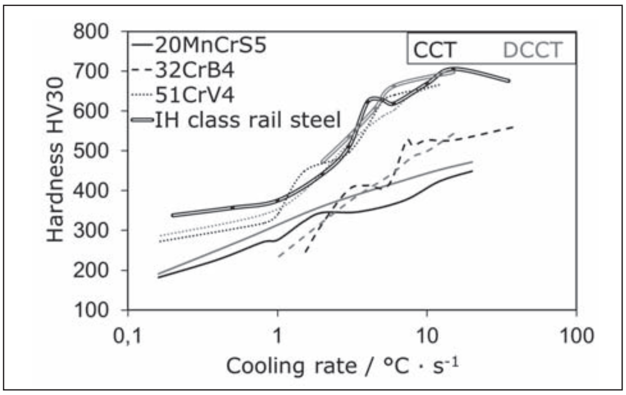

Figure 6 Influence of the cooling rate on the hardness HV30 of selected steels.

Transformation of austenite to ferrite did not take place in this steel, since composition of this steel is due to higher content of carbon and of other elements closer to the eutectoid composition [2]. As a result of deformation the bainitic transformation was also slightly accelerated and moreover its area was enclosed.

The temperature of the start of martensitic transformation was as a result of deformation shifted down similarly as in the steel D - IH class Rail Steel [12] – see Figure 4. However, in this steel, which has the highest carbon content of all four tested steels, no significant acceleration of pearlitic transformation took place. Bainitic transformation was also rather decelerated as a result of previous deformation.

Author F. Nürnberger et al. [1] explains the phenomenon of deceleration of pearlitic transformation caused by previous deformation by the fact, that comparatively long time intervals from the start of deformation till the start of pearlite formation lead to suppression of the effect of deformation, thus no significant acceleration of pearlitic transformation need not take place, rather on the contrary this transformation may be slightly decelerated, but the resulting pearlite should be finer.

Independent of deformation on the start of martensitic transformation in the investigated steels is presented by mean values, including the measured deviations – see Figure 5.

Comparison of the measured hardness (Figure 6) confirms that steels with higher carbon content achieve higher values of hardness [2].

Moreover in all cases, with the exception of selected segments, where transformations took place, the hardness increased with the increasing cooling rate.

SUMMARY

In the steels 20MnCrS5, 32CrB4, 51CrV4 the fact, that previous deformation would cause an acceleration of ferritic and pearlitic transformations, i.e. of transformations controlled by diffusion, was confirmed. Moreover, in these three steels the influence of the previous deformation caused also an acceleration of bainitic transformation, the kinetics of which depends primarily on chemical composition of the steel [2]. What concerns the influence of deformation on martensitic transformation, in this case it is possible to assume, that particularly the cooling rate plays the crucial role in this case [3]. In case of higher cooling rates the temperature of the start of martensitic transformation decreases, while in case of slower cooling rates the temperature of the start of martensitic transformation becomes equal to that of non-deformed samples, or it is even slightly higher. In case of the steel IH class Rail Steel the previous transformation did not cause any acceleration of pearlitic transformation, since too long time between deformation and pearlitic transformation caused a coarsening of the original austenitic grains.

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