STUDY OF KINETICS PHASE TRANSFORMATIONS AFTER PLASTIC DEFORMATION OF RAIL STEEL CLASS IH ALLOYED WITH CHROMIUM

KAWULOK Rostislav[1], SCHINDLER Ivo[1], KAWULOK Petr[1], KAWULOK Vojtěch[1], PODOLÍNSKÝ Petr[2], KUREK Václav[2], RUSZ Stanislav[1], OPĚLA Petr[1]

[1]*VSB - Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Ostrava, Czech Republic, EU*
rostislav.kawulok@vsb.cz, ivo.schindler@vsb.cz, petr.kawulok@vsb.cz, vojtech.kawulok.st@vsb.cz, stanislav.rusz2@vsb.cz, petr.opela@vsb.cz
[2]*TŘINECKÉ ŽELEZÁRNY, a. s., Třinec, Czech Republic, EU*
Petr.Podolinsky@trz.cz, Vaclav.Kurek@trz.cz

Abstract

The paper is aimed at evaluation of effect previous plastic deformation on transformation kinetics of rail steel class IH alloyed with chromium. The CCT and DCCT diagrams were assembled on the basis of dilatometric tests with and/or without an influence of the previous deformation. To the experiment execution the dilation module of the plastometer Gleeble 3800 was used. The Accuracy of the diagrams was faced with metallographic analysis and measurement of hardness. The obtained results were compared with the results of in-process measurement of rail rolling mill Třinecké železárny Inc. This confirmed the theory that in the case of steels which are intended for rolling rails, no influence of the previous deformation the crucial influence pearlitic transformation in terms of time, but in the case of higher cooling rate has deformation an appreciable effect on shift temperature intervals of pearlite formation.

Keywords: Rail steel, phase transformation of steel,CCT and DCCT diagrams, dilatometric tests, Gleeble 3800

1. INTRODUCTION

The rails rolled in the company TŘINECKÉ ŽELEZÁRNY a.s. (TŽ a.s.) belong, thanks to their quality and usability among strategic products not only of the Trinec metallurgical plant but also of the entire Czech metallurgical industry. The rails thus belong to the assortment of the rolled products, which are subject to the highest requirements with regard to both structure and also their mechanical properties and surface quality. For these reasons, an effort aimed at development and optimisation of technologies of controlled cooling of these rails is being developed. These optimisation trends are, however, conditioned by the knowledge of kinetics of phase transformations during cooling and possibilities of influencing them [1-6].

A suitable tool for this purpose are mainly transformation diagrams of various steels. The diagrams of the type CCT (Continuous Cooling Transformation) are used most frequently and widely for all technologies dealing with cooling of steel. However, in the case when the cooling process is directly preceded by deformation processes (such as rolling, forging, etc.), the diagrams of the type DCCT (Deformation Continuous Cooling Transformation), i.e. diagrams comprising in the transformation kinetics also the influence of the previous deformation conditions are a more appropriate instrument [7-9].

In this paper, attention was paid to the study of the kinetics of phase transformations with consideration of the effect of the previous deformation on the rail steel of the IH grade alloyed with. The steel grade IH (Intermediate Hardness) is designed for rolling of the railway rails with the requirement to ensure the surface hardness of the head at the level of 325 to 380 HB. These rails are intended for use for higher levels of the axle loads, mainly in the sector of freight transportation in the North America continent. This steel belongs by its chemical composition among the high carbon chromium-manganese steels with added molybdenum. The carbon content of this steel varies close to the boundary of a eutectoid composition [1, 2, 4].

The rolling and subsequent treatment of this type of rails are performed also on the upgraded reversing mill of the company TŽ a.s., where in 2014 a device enabling intense cooling of the top of the rail head was installed on the existing cooling grid. The cooling uses two fans, which pump air into the diffusers, which accurately dose the incoming air on the rail heads along their entire length [3].

2. EXPERIMENT DESCRIPTION

For assessment of the transformation kinetics of the investigated steel during cooling transformation diagrams of the types CCT and DCCT were constructed, i.e. without and with the influence of the previous deformation. The transformation diagrams were constructed on the basis of dilatometric analyses supported by metallographic analyses and hardness measurements. Dilatometric tests were performed with the use of the optical dilatometer module (**Figure 1**), which was retrofitted on the plastometer GLEEBLE 3800, already available at the VŠB - Technical University of Ostrava (VŠB-TU Ostrava), Faculty of Metallurgy and Materials Engineering (FMME) - Department of materials forming; CZECH REPUBLIC [9].

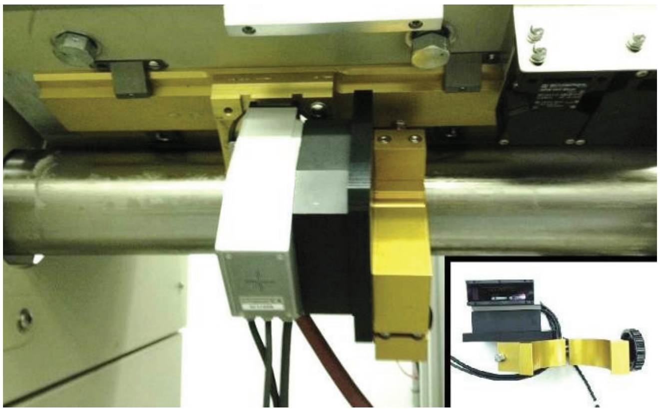


Figure 1 Optical dilatometrics module of plastometer Gleeble 3800

For the experiment cylindrical samples of the type SICO with diameter of 6 mm and length of 86 mm were made from the rail steel class IH alloyed wih chromium, the chemical composition is specified in **Table 1**. The length of heated zone of these samples was 20 mm [4].

Table 1 Chemical composition of the investigated rail steel in wt. % [4]

C	Si	Mn	P	S	Cr	Ni	Mo	Al	N
0.794	0.552	1.03	0.016	0.008	0.67	0.03	0.009	0.003	0.004

The prepared samples were resistance heated at the constant rate of 10 °C / s to the austenitizing temperature of 960 °C, which corresponded to the conditions in the finish rolling of the rails at the company TZ a.s. [4]. In the case of construction of the CCT diagram, this was followed by a dwell at this temperature for 300 seconds and by subsequent cooling down to room temperature at constant cooling rates. The range of the cooling rates was chosen in a way to enable a description of the all the transformations in the investigated steel. In the case of construction of the DCCT diagram, the dwell at the heating temperature was followed by deformation by a uniaxial pressure of 0.35 and strain rate of $1 s^{-1}$. The pressing of the sample was immediately followed by controlled cooling at constant rates selected again in the range necessary for the description of all the transformation of the steel. The evolution of the tests realised on the dilatometric module of the plastometer GLEEBLE 3800 is shown in diagrams in **Figure 2** for the tests without deformation, and in **Figure 3** for the tests with the influence of deformation.

The data obtained from dilatometric tests were moreover confronted also with the metallographic analyses, including measurement of the HB hardness.

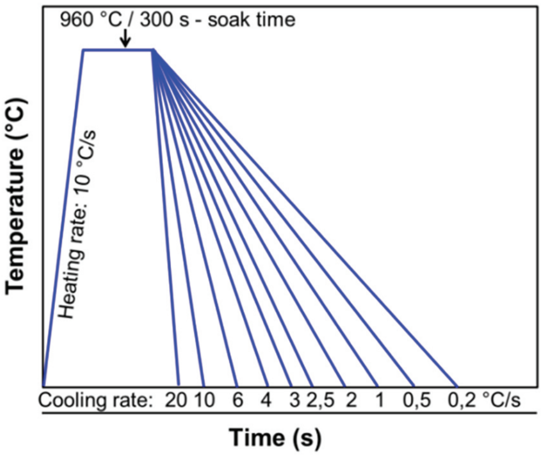


Figure 2 Scheme of plastometers tests flows (without deformation)

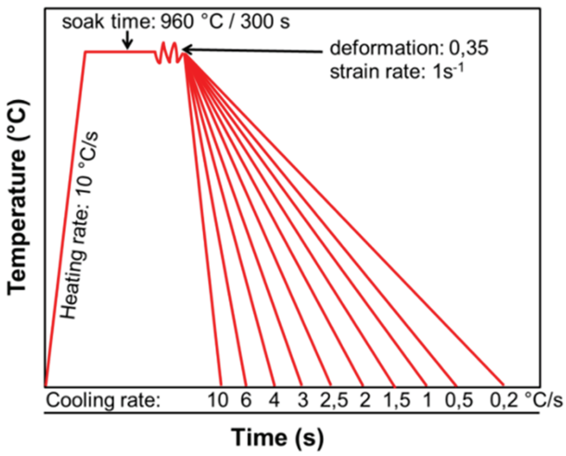


Figure 3 Scheme of plastometers tests flows (with the previous deformation)

3. DISCUSSION OF RESULTS

3.1. Dilatometric tests without previous deformation

Due to the fact that this steel is by its chemical composition close to a eutectoid point or to the slightly hyper-eutectoid point, an occurrence of hypo-eutectoid ferrite in the structure was not expected. This assumption was confirmed by dilatometric tests, as well as subsequent metallographic analyses. We thus identified in the structure only pearlite and martensite. The CCT diagram of the investigated steel is presented in **Figure 4**. Somewhat unusual is the absence of bainite in the structure. However, this phenomenon may have been caused by the combination of the increased content of carbon, manganese and chromium, the increased share of which resulted in a delay of the bainitic transformation and even in its suppression. The influence of the selected admixtures, including chromium, on the shift of the areas of transformations in the CCT diagram, is shown in **Figure 5** [7, 8, 10-12].

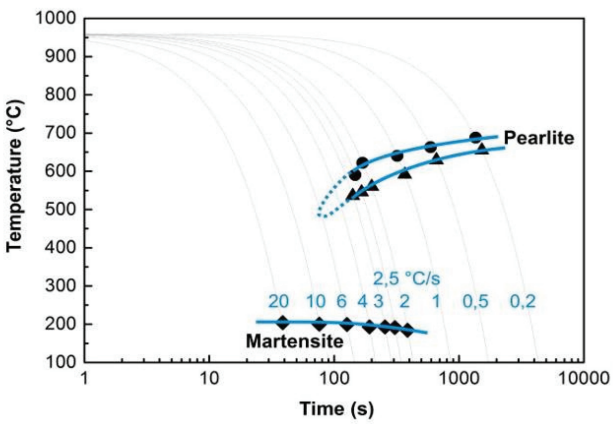


Figure 4 CCT diagram of the investigated rail steel

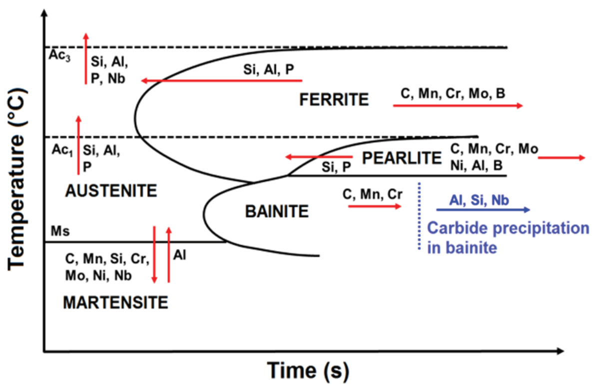


Figure 5 Effect of alloying on the ferrite, pearlite, bainite and martensite transformation [10]

On the basis of a detailed analysis of the CCT diagram in **Figure 4** it can be stated that the area of formation of pearlite begins from the cooling rate of 6 °C / s and then its share in the structure increases with the decreasing cooling rate. While within the range of the cooling rate from 6 to 2 °C / s a significant share of martensite also occurs in the structure, at the cooling rates below 2 °C / s the structure consists only of the pearlite. The martensite begins to form in this steel at relatively low temperatures, which is, however, given by the carbon content in the steel. It is known that the higher the carbon content in the steel, the lower the temperature of the beginning of the martensite formation [7, 9, 11, 12].

The influence of the increased share of manganese and chromium on the suppression of the bainitic transformation has already appeared in several works. Its confirmation may be found also in the research of the authors LI Xiao-Fei et al., who assessed the effect of chromium content on the shift of the area of formation of pearlite in the CCT diagram rail on the steel of similar composition, see **Figure 6**. In this case too, the CCT diagram of the rail steel did not contain a bainitic area, which confirms the considerable dependence of this transformation on the chemical composition of the steel [12].

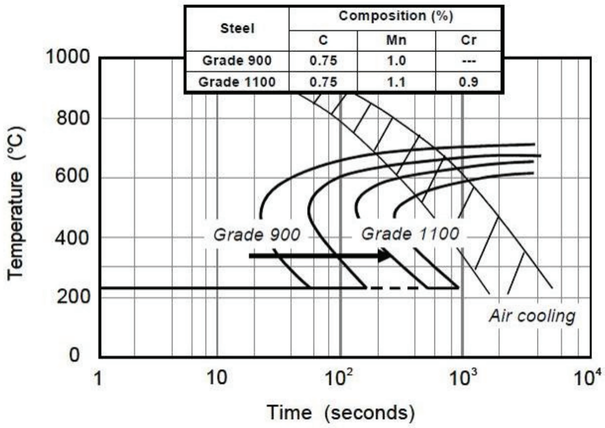


Figure 6 CCT - diagram showing the effect of alloying to pearlite transformation [12]

3.2. Dilatometric tests with previous deformation

In the next stage of the experiment, a DCCT diagram of investigated rail steel was constructed, which is shown in **Figure 7**. As it can be seen from the DCCT diagram, here too no other phases than pearlite and martensite were detected. The nose of pearlitic nose area was again lying on the curve of the cooling rates of 6 °C / s and up to the cooling rate of 1.5 °C / s the structure was formed by a mixture of pearlite and martensite. The temperature of the beginning of the martensite formation was lying here too closely to 200 °C.

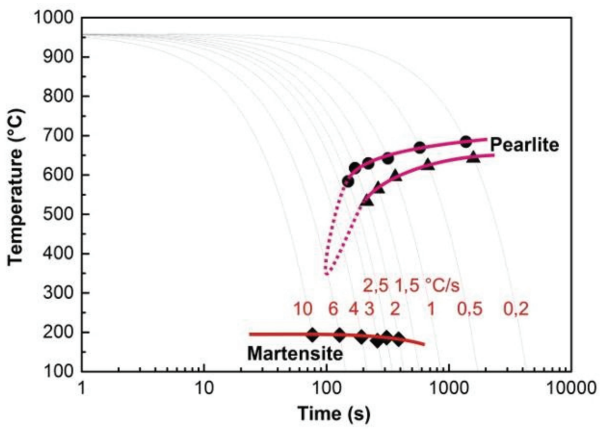


Figure 7 DCCT diagram of investigated rail steel

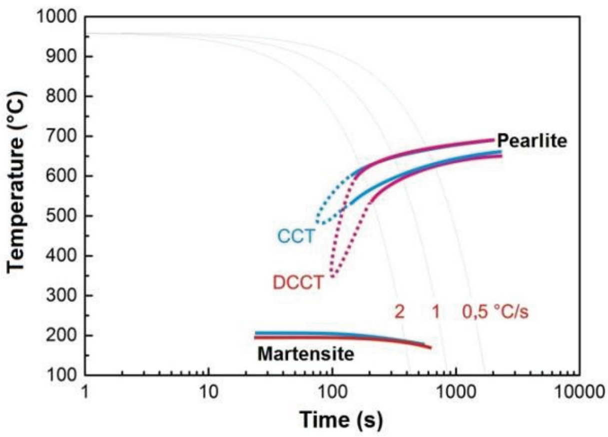
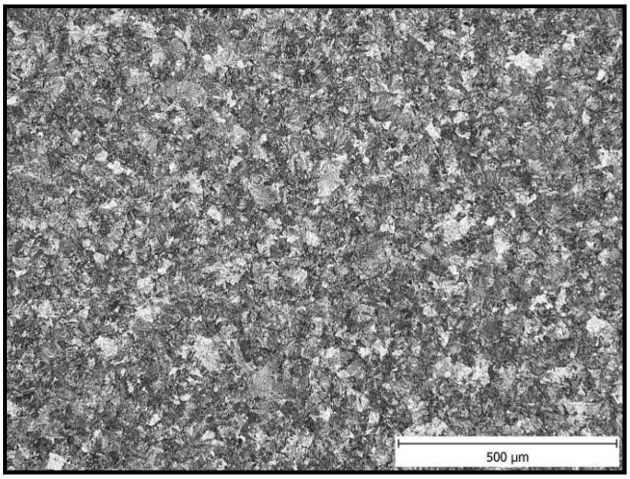


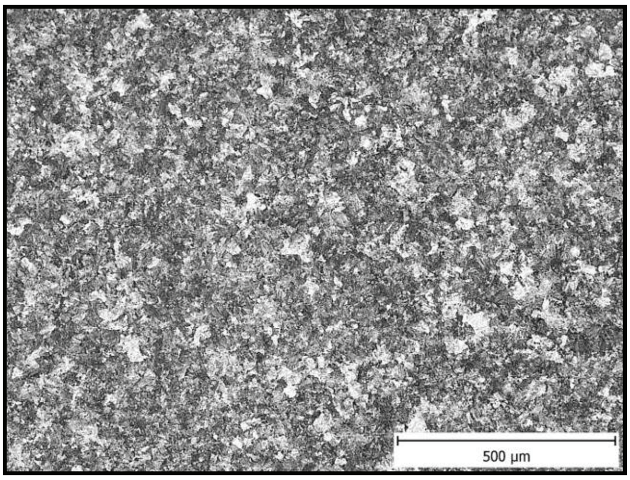
Figure 8 Comparison of CCT and DCCT transformation diagrams of investigated rail steel

However, for an easier detection of the influence of the previous deformation, we constructed a comparative diagram in **Figure 8**, from which it is clear that both diagrams differ only by the shape of the nose of the pearlitic area. This is given by the fact that the deformation in the case of the DCCT diagram was ran at the temperature high enough for recrystallization of the austenitic grains and before the phase transformation it coarsened probably to the size very similar to the grain size obtained by direct austenitization at the temperature of 960 °C (for the CCT diagram). It can also be mentioned that the curve of the beginning of the martensitic transformation slightly decreased under the influence of deformation, particularly in the areas of higher cooling rates. This diagram in **Figure 8** moreover shows the area of real cooling rates (0.5 - 2 °C / s) of the rails at the company TŽ a.s. It can be seen from this diagram that in the said range of the cooling rates the previous deformation under the given conditions does not play any significant role [3, 4, 7].

As a result of the previous plastic deformation, therefore, no acceleration of the pearlite transformation took place, which contradicts the proposition that due to the deformation the transformations controlled by diffusion get shifted to the left towards shorter times but however as a result of deformation the resulting pearlite may have a finer structure. This assumption is confirmed by metallographic micrographs in **Figure 9**, from which it is seen that the structure after cooling at the cooling rate of 1 °C / s unaffected by previous deformation (**Figure 9 a**) has a slightly larger pearlite grains in comparison with the structure influenced by deformation after an identical cooling rate (**Figure 9 b**) [1, 7, 9, 11].



a) cooling rate 1 °C / s - without deformation



b) cooling rate 1 °C / s after deformation

Figure 9 Examples of microstructure of the samples subjected to dilatometric tests

3.3. Influence of deformation on the hardness

The hardness values very accurately correspond to the shares of pearlite and martensite determined by metallography. The effect of the previous deformation is very small, it is more or less noticeable only for medium cooling rates, associated with the occurrence of the final two-phase structure. Diagram of hardness is shown in **Figure 10**.

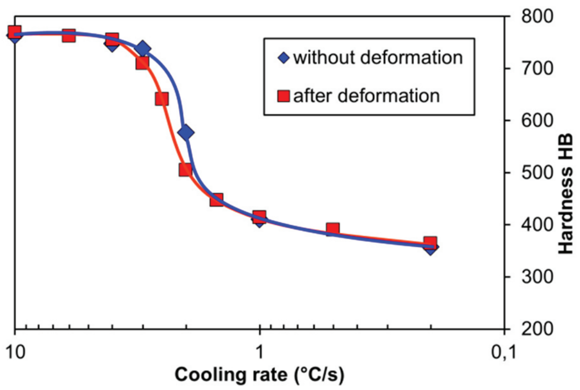


Figure 10 Effect of cooling rate on the hardness of the samples after dilatometry of IH class rail steel

4. CONCLUSIONS

The transformation diagrams of the type DCCT and CCT of the investigated IH rail steel alloyed with chromium have high degree of agreement in the industrially usable area of relatively low cooling rates, which is caused by the high temperature of austenitization (960 °C) at dilatometric tests. This temperature corresponds to the industrial finish rolling temperature. The DCCT diagram shows therefore only little influence by the previous deformation because the formed austenitic structure has time not only for recrystallization but probably also for coarsening, which completely eliminates the effect of the previous strain hardening. The only major differences can be observed in the shape of the nose of the pearlitic area, which is after deformation compressed towards the lower temperatures.

ACKNOWLEDGEMENTS

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