P. OPĚLA, Z. SOLOWSKI, K. M. ČMIEL

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# EFFECT OF DEFORMATION ON THE CONTINUOUS COOLING TRANSFORMATION (CCT) DIAGRAM OF STEEL 32CRB4

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CCT and DCCT steel diagrams of the steel 32CrB4 were determined by the universal plastometer GLEEBLE 3 800 on the basis of dilatometric tests. Dilatometric analysis showed that compared to the diagram provided by the software QTSteel the noses of individual curves are in fact shifted towards shorter times. Preceding deformation significantly affected the decay diagram of the investigated steel. Shorter times, which were available for recovery of the deformed structure during more rapid cooling, resulted in a significant shift of the curves in the DCCT diagram towards shorter times. At low cooling rates the effect of deformation was practically negligible, since recrystallization took place between the deformation and beginning of the phase transformation.

*Key words:* steel 32CrB4, deformation, cooling, dilatometric tests, CCT and DCCT diagrams

## INTRODUCTION

Transformation diagrams illustrate the effect of temperature and time on the course of transformation of austenite [1-4]. These diagrams are used particularly at optimisation of procedures of thermal or thermo-mechanical treatment [5].

Several works have been proved that effect of plastic deformation on austenite transformation shortens times of transformation evolution [6, 7]. It can be therefore generally assumed that DCCT diagrams will shift towards shorter times in comparison with CCT diagrams [6-10].

This paper focuses on investigation of the influence of deformation on CCT diagram of the steel 32CrB4 used for manufacture of screws [11]. For construction of CCT and DCCT diagrams we used dilatometric tests made on universal plastometer Gleeble 3 800 installed at the Technical University of Ostrava (RMSTC, VSB-TU Ostrava) [12]. These diagrams were compared with those received by calculation in the software QTSteel.

## EXPERIMENTAL PROCEDURE

Two types of samples were prepared for dilatometric tests from the 32CrB4 steel with chemical composition according to the standard EN 10263-4 [11] – see Table 1.

Table 1 **Chemical composition of steel 32CrB4 / wt. % [11]**

| C | Mn | Si |
|---|---|---|
| 0,30 – 0,34 | 0,60 – 0,90 | max. 0,30 |
| Cr | P | S |
| 0,90 – 1,20 | max. 0,025 | max. 0,025 |

For dilatometric tests without deformation the samples were prepared with a diameter of 10 mm and a total length of 84 mm with a hollow parts of head and with reduced central part of the sample with diameter of 5 mm and length of 5 mm. This type of samples is not suitable for applications of compressive deformation, and thus for dilatometric tests with influence of deformation we selected cylindrical type samples of the type SICO with diameter of 10 mm and length of the heated section of 20 mm.

Prepared samples were heated by electrical resistance to the temperature of 850 °C, followed by a 2 minute dwell at this temperature. The samples were then cooled at the chosen cooling rate to the temperature of 25 °C. For dilatometric tests without preceding deformation we chose the cooling rates of 37,2 – 15 – 10 – 8 – 7,3 – 5,5 – 4 – 3 – 2 – 1,5 – 1 – 0,4 – 0,16 °C/s.

In case dilatometric tests with effect of preceding deformation the samples were after heating and dwell at the temperature deformed at the temperature of 850 °C by uniaxial pressure by true strain of 0,35 at the strain rate of 1 $s^{-1}$, and then cooled by chosen cooling rates (15 – 12 – 10 – 8 – 5,5 – 3 – 1 – 0,16 °C/s) to the temperature of 25 °C.

Additionally we performed 5 dilatometric tests with effect of preceding deformation, when after analogical austenitisation of the samples as in the previous case, the samples were cooled by chosen cooling rates to the temperature of 800 °C, and after dwell of 10 s they were deformed by the true strain of 0,35 at the strain rate of 1

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R. Kawulok, I. Schindler, P. Kawulok, S. Rusz, P. Opěla, - VŠB – Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Czech Republic
Z. Solowski, K. M. Čmiel - Třinecké železárny a.s., Czech Republic

$s^{-1}$. The samples were then cooled by chosen cooling rates (15 – 8 – 5,5 – 3 – 1 °C/s) to the temperature of 25 °C.

The test samples were then subjected to metallographic analyses and measurements of the HRC hardness.

## DISCUSSION OF RESULTS

First we performed dilatometric tests of the steel 32CrB4 at chosen cooling rates without the effect of preceding deformation.

On the basis of determined dilatation curves we constructed using the specialised CCT software, which is fully compatible with the plastometer Gleeble 3 800 [12], the CCT diagram of the investigated steel - see Figure 1.

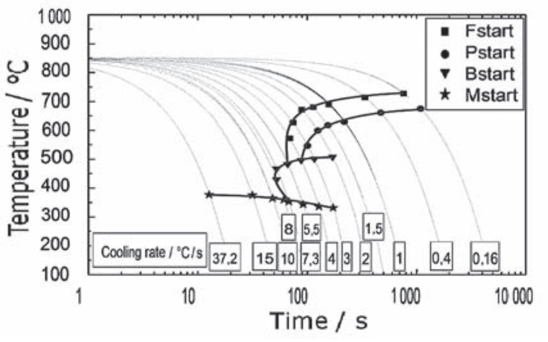


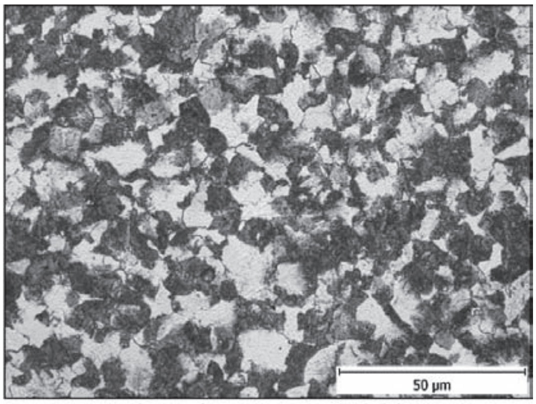
**Figure 1** CCT diagram of steel 32CrB4 (without effect of preceding deformation)

With use of optical metallographic analysis, it was found that after cooling from the austenitisation temperature of 850 °C at the rate below 1,5 °C/s structure is composed entirely of ferrite and pearlite – see Figure 2a. Cooling rates exceeding 7,3 °C resulted in formation of structures consisting of turbidity phases (bainite and martensite) - see Figure 2b.

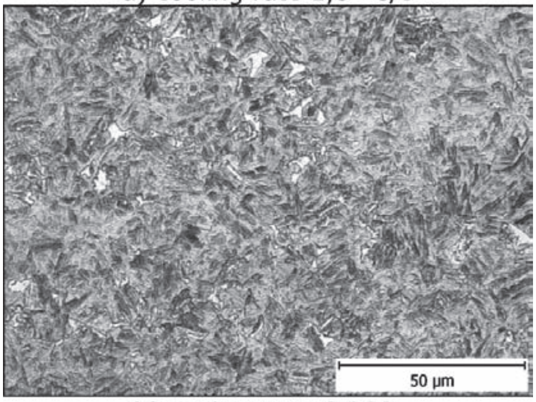
For comparison we constructed for analogical conditions a CCT diagram of investigated steel using the computational software QTSteel - see Figure 3.

Agreement of experimentally determined CCT diagram with the diagram obtained by calculation (see Figures 1 and 3) is insufficient. Decay diagram constructed by calculation in the QTSteel software does not reflect the drop in temperature of the beginning of martensitic transformation with the decreasing cooling rate [6]. In addition, the noses of individual structural phases are in the case of calculated CCT diagram shifted towards longer times.

The experimentally constructed DCCT diagram of the investigated steel is documented in Figure 4. Since no effect of temperature of deformation on the temperature of transformation was found, the points obtained for the deformation temperature of 850 and 800 °C were interspersed together with the respective curves.



a) cooling rate 1,5 °C/s



b) cooling rate 8 °C/s

**Figure 2** Examples of microstructure of the samples subjected to dilatometric tests

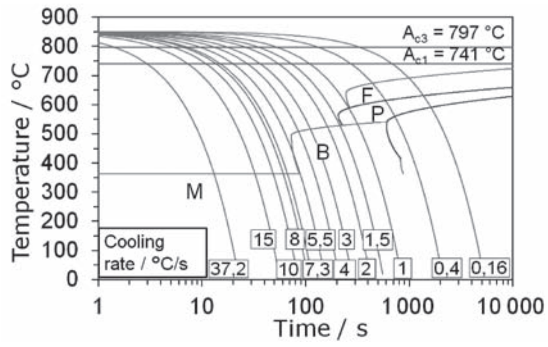


**Figure 3** CCT diagram of steel 32CrB4 constructed by using the software QTSteel

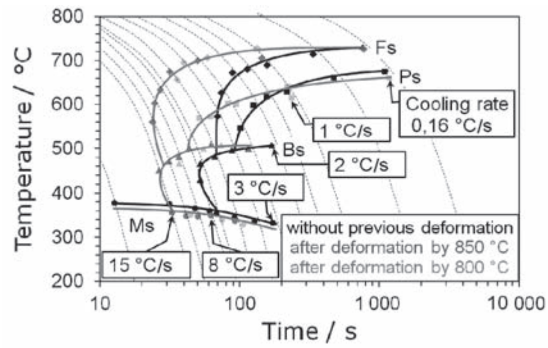
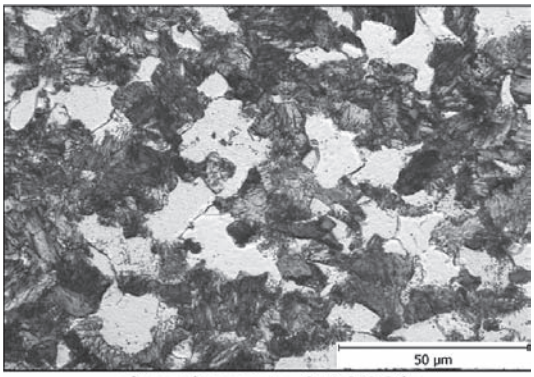
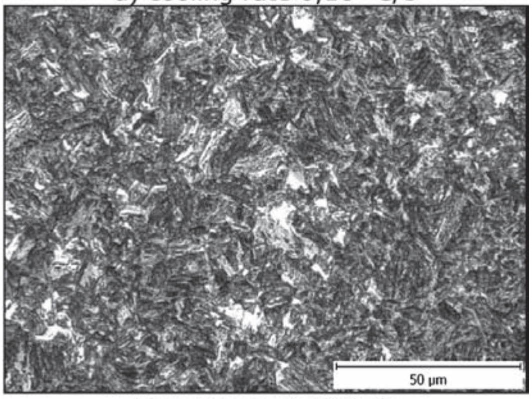


**Figure 4** Effect of deformation in the CCT diagram for the steel 32CrB4

At low cooling rates, the effect of deformation was practically negligible, since recrystallisation took place between the beginning of deformation and the beginning of the phase transformation, which eliminated previous strain hardening - see the microstructure of the sample cooled at the cooling rate of 0,16 °C/s (Figure 5a). Shorter times, which were available for recovery of deformed structure during more rapid cooling (cooling rate of 3 °C/s) resulted in a significant shift of the curves in DCCT diagram to the left, i.e. to the shorter times. This concerns the beginning of the bainite and pearlite transformation, but most significantly the beginning of austenite transformation to ferrite. That's why the resulting microstructure of the strain hardened sample cooled at the cooling rate of 8 °C/s was formed of a mixture of martensite, bainite, pearlite and ferrite, while the sample cooled at analogical cooling rate without preceding deformation contained only a mixture of turbidity phases with minimal occurrence of ferrite - see Figures 5b and 2b.



a) cooling rate 0,16 °C/s



b) cooling rate 8 °C/s

**Figure 5** Examples of microstructure of the deformed samples subjected to dilatometric tests

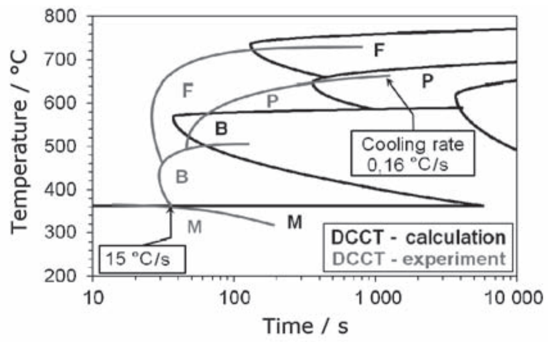


**Figure 6** Comparison of experimentally determined and calculated DCCT diagrams of investigated steel

For completion we compared experimental DCCT diagrams with those obtained by calculation (in the program QTSteel) - see Figure 6.

It is evident from Figure 6 that in the case of the steel 32CrB4 the program QTSteel does not provide useful information about the effect of deformation on the kinetics of phase transformations during cooling at various cooling rates from the temperature of 850 °C (which was also the temperature of deformation).

It was determined by analysis of shares of phases analysis phases in the samples without preceding deformation that at cooling rates of 3 and 4 °C/s the structure is formed of 10 % of martensite, up to 66 % by bainite, up to 11 % by pearlite and up to 13 % by ferrite, whereas at cooling rates exceeding than 7,3 °C/s the structure consists only of turbidity phases.

In the case of dilatometric samples affected by previous deformation the structure was after cooling rates from 3 to 8 °C/s formed by a mixture of martensite, bainite, pearlite and ferrite, at higher cooling rates then only by a mixture of martensite and bainite.

Average HRC hardness according to Rockwell of dilatometrically tested samples, as well as hardness determined by calculation in the QTSteel program are documented by diagram in Figure 7.

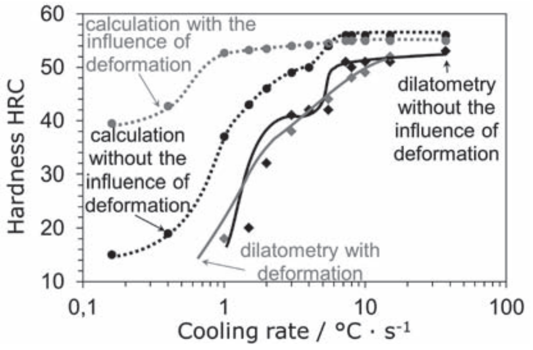


**Figure 7** Hardness of the samples subjected to dilatometric tests and calculated by using the software QTSteel

Calculation performed by the program QTSteel determined in comparison with dilatometrically tested samples substantially higher effect of deformation on hardness of the steel 32CrB4 in the investigated range of cooling rates. Hardnesses determined by calculations were significantly higher then hardnesses samples tested dilatometrically.

## SUMMARY

CCT and DCCT diagrams of the steel 32CrB4 were constructed with use of dilatometric tests performed on the plastometer Gleeble 3 800.

It was verified that the decay diagram created by calculation in the program QTSteel did not reflect the drop of temperature of the beginning of martensitic transformation with decreasing cooling rate, and in comparison with the dilatometric results the noses of individual curves were shifted to longer times, which is particularly striking in the case of formation ferrite and pearlite.

Preceding deformation significantly affects the decay diagram. Shorter times, which were available for recovery of the deformed structure during more rapid cooling resulted in a significant shift of the curves in the DCCT diagram towards shorter times. At low cooling rates, the effect of deformation was practically negligible, since recrystallisation took place between the beginning of deformation and the beginning of phase transformation.

Metallographic analyses and hardness tests confirmed the accuracy of dilatometric analyses performed on the plastometer Gleeble 3 800.

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**Note**: The translator responsible for English language is B. Škandera, Dobrá, Czech Republic