EFFECT OF PLASTIC DEFORMATION ON CCT DIAGRAM OF SPRING STEEL 51CrV4

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Abstract

The paper is aimed on appraisal of influence of preceding deformation on spring steel CCT diagrams, which were created on the basis on dilatometric analyses of cooling curves, using universal plastometer Gleeble 3800, CCT and DCCT diagrams after austenitisation at the temperature of 850 °C, which were further supported by metallographic analyses and hardness measurements HV30. Dilatometric tests were performed at different cooling rates in the range from 0.16 to 12 °C/s. The diagrams prepared in this way were compared with the diagrams computed numerically by the specialised software QTSteel under the same conditions. The comparison of the experimentally obtained diagrams with the numerically computed ones confirms irreplaceability of physical experiments due to big differences between reality and numerically computed diagrams. The influence of preceding deformation on anisothermal disintegration of austenite was manifested at each phase transformation, but in case of pearlitic transformation it was the most outstanding due to significant acceleration.

Keywords: Spring steel 51CrV4, dilatometric tests, CCT and DCCT diagrams, plastometer Gleeble 3800

1. INTRODUCTION

Efforts aimed at optimisation of the existing processes and implementation of new technologies of cooling, connected with processes of controlled cooling of steel as such, cannot be put into life without knowledge of phase transformation kinetics [1, 2]. CCT and DCCT diagrams are suitable tool for description of exactly this kinetics of super-cooled austenite. Knowledge of those diagrams is very useful as control of steel structure at the phase of their cooling after hot forming, or at their heat treatment connected with phase transformations [1-6].

Classical CCT diagrams describe kinetics of austenite transformation in idle mode, this state is in practice, however, often influenced by the preceding deformation, which to certain extent affects kinetics of individual austenite transformations during cooling. This can be described by DCCT diagrams, which comprise the influence of preceding deformation [6-8]. DCCT diagrams can be constructed only on the basis of dilatometric tests with influence of preceding deformation with use of special dilatometers, or possibly by software specially developed for this purpose [5, 9-11].

The aim of experiment consisted in determination of CCT and DCCT diagrams for spring steel 51CrV4 on the basis of dilatometric tests, which were performed on plastometer Gleeble 3800, installed at the Regional Materials Science and Technology Centre (RMSTC) at the VSB - Technical University of Ostrava (VSB-TU Ostrava) [12]. Thus obtained transformation diagrams were compared with diagrams obtained by numerical calculation in the program QTSteel 3.2. [9].

The steel 51CrV4 is slightly hypo-eutectoid low alloyed chromium - vanadium steel, which is characterised by high hardening capacity, and which is suitable for heavily loaded machine parts. In heat treated state it has very favourable ratio of strength to yield point, but it has, however, lower toughness in comparison with Cr-Mo steels. It is characterised by high values of fatigue limits at cycling stressing, that's why it is suitable also for manufacture of heat treated springs [4, 13, 14].

2. EXPERIMENT DESCRIPTION

For the experiment cylindrical samples of the type SICO with diameter of 6 mm and length of 86 mm were made from the spring steel 51CrV4, the chemical composition is which according to the norm EN 10083-3 [14] is specified in **Table 1**. The length of heated zone of these samples was 20 mm [12, 15].

Table1 Chemical composition of steel 51CrV4 according to the standard EN 10083-3 in wt. % [12]

C	Si	Mn	P	S	Cr	V
0.47 - 0.55	max. 0.40	0.70 - 1.10	max. 0.025	max. 0.035	0.90 - 1.20	0.10 - 0.25

These samples were at first used for a study aimed at determination of suitable austenitisation temperature. This experiment was performed on dilatometric module of the plastometer Gleeble 3800, when the samples were heated at the heating rates of 1 and 10 °C/s. Temperatures of phase transformations Ac_1 and Ac_3 were determined form the obtained dilatometric curves. Determination of the values of transformation temperatures in dependence on the heating rate is illustrated in **Fig. 1**. On the basis of the values determined from **Fig. 1** the optimal austenitisation temperature was set to be 850 °C.

The same samples and the same instrumentation were afterwards used for dilatometric tests with and without influence of preceding deformation. In the case of dilatometric tests without influence of preceding deformation the samples were heated to the temperature of 850°C, which was followed by a dwell of 120 s at this temperature. The samples were then cooled down at constant cooling rates ranging from 0.16 to 12 °C/s. The samples were cooled down by heat removal into copper jaws.

In the next phase dilatometric tests with influence of preceding deformation were performed in a similar way, with the difference consisting in the fact that heating to the temperature of 850 °C with the dwell of 120 s at this temperature was followed by deformation by uniaxial compression. Magnitude of real strain was 0.35 at the strain rate of 1 s^{-1}. The samples were then again cooled down at constant cooling rates ranging from 0.16 to 12 °C/s.

All dilatometric tests were confronted with metallographic analyses and with measurement of hardness HV30.

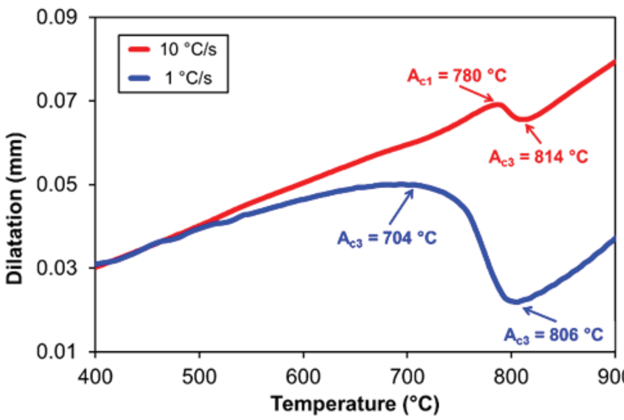


Fig. 1 Determination of transformations temperatures

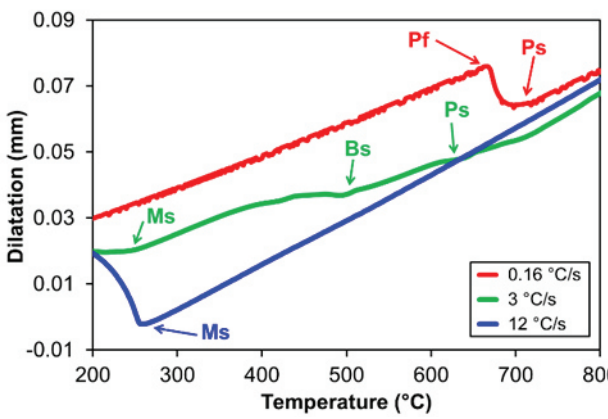


Fig. 2 Dilatation curves for cooling of the spring steel 51CrV4 (without of preceding deformation)

3. DISCUSSION OF RESULTS

3.1. Dilatometric tests without preceding deformation

Determination of optimal austenitisation temperature (850 °C) for the steel 51CrV4, was followed by dilatometric tests without influence of preceding plastic deformation. **Fig. 2** presents an example of dilatation curves during cooling of samples at various cooling rates.

From obtained dilatation curves a CCT diagram of the examined steel without influence of preceding deformation (**Fig. 3**) was constructed by the specialised CCT software, supplied by the company DSI together with the plastometer Gleeble 3800 [15]. In order to enable a comparison, an analogical CCT diagram was calculated for identical experimental conditions by the software QTSteel 3.2., provided by the company ITA s.r.o. (**Fig. 4**) [9].

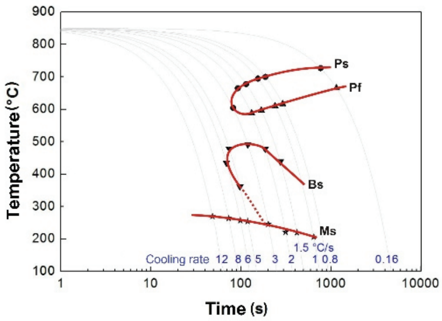


Fig. 3 CCT diagram of steel 51CrV4

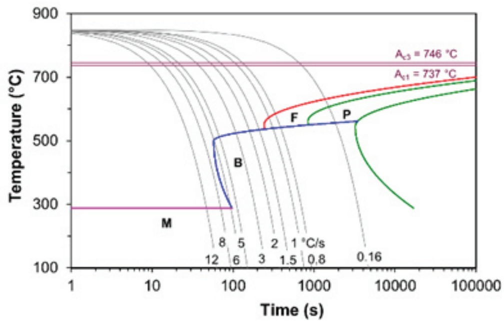


Fig. 4 CCT diagram of steel 51CrV4 constructed by using the software QTSteel 3.2.

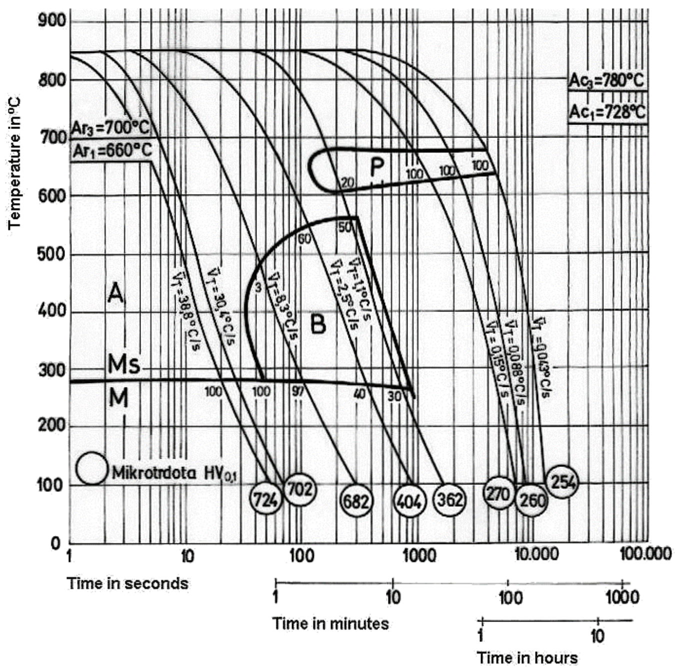
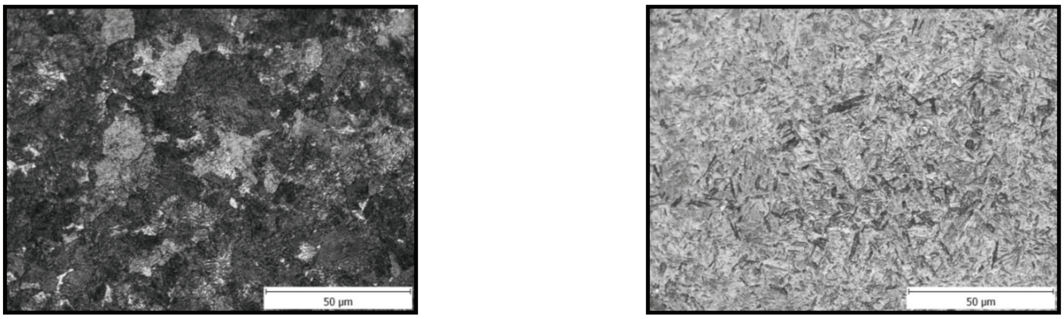


Fig. 5 CCT diagram of equivalent steel 50CrV4 [16]

It is evident, that CCT diagram prepared by mathematical modelling (**Fig. 4**) significantly differs from experimental reality (**Fig. 3**). The most essential difference consists in the fact that mathematically constructed CCT diagram assumes on the basis of chemical composition a formation of considerable portion of ferrite during cooling. This assumption seems to be logical, as this steel is hypo-eutectoid [14], it is, however, in conflict with the reality ascertained by dilatometric tests. This fact is supported also by CCT diagram of equivalent steel 50CrV4 (**Fig. 5**), which is similar to the examined steel by its chemical composition and utilisation [16]. This diagram in **Fig. 5** is also formed only by curves of pearlitic, bainitic and martensitic transformation. Another substantial deficiency of the program QTSteel 3.2. is termination of the start of martensitic transformation at the point of contact with the curve of the start of bainite formation. The program QTSteel moreover does not accept an assumption of drop of temperature of the start of martensitic transformation with decreasing cooling rate, or with increasing time. It is evident from comparison of the CCT diagram of the examined steel determined by dilatometry (**Fig. 3**) with the diagram of similar type of steel (**Fig. 5**), that both diagrams are quite similar from the perspective of the shape of curves and temperatures. Nevertheless, in case of diagram of the steel 50CrV4 the start of bainitic transformation is shifted more to the left, towards shorter times.

Correctness of the CCT diagram prepared by dilatometry was verified by optical metallographic analysis. In the case of very small cooling rates the structure was formed particularly by pearlite with small islands of ferrite with toal share up to 5 %, which is below the limit of detection by dilatometry (**Fig. 6a)**) [15]. **Fig. 6b)** shows micro-structure of the sample after dilatometry without deformation after cooling at the cooling rate of 6 °C/s. The structure is in this case predominantly by martensite, while bainite is a minority component.



a) cooling rate 0.16 °C/s   b) cooling rate 6 °C/s

Fig. 6 Examples of microstructure of the samples subjected to dilatometric tests (without deformation)

3.2. Dilatometric tests with preceding deformation

In the next step also a DCCT diagram was constructed experimentally on the basis of dilatometry - see **Fig. 7**. In this case too, for the purposes of comparison a DCCT diagram was created by numerical calculation in the software QTSteel 3.2. - see **Fig. 8**.

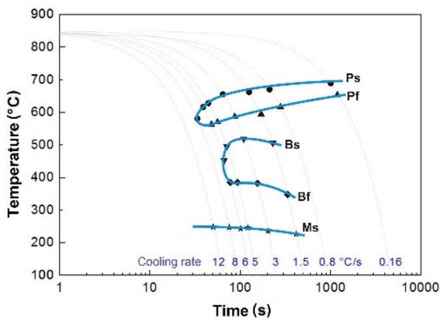


Fig. 7 DCCT diagram of steel 51CrV4

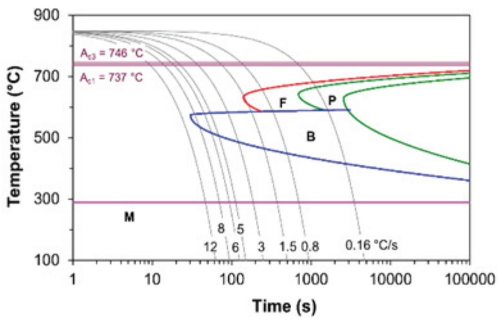
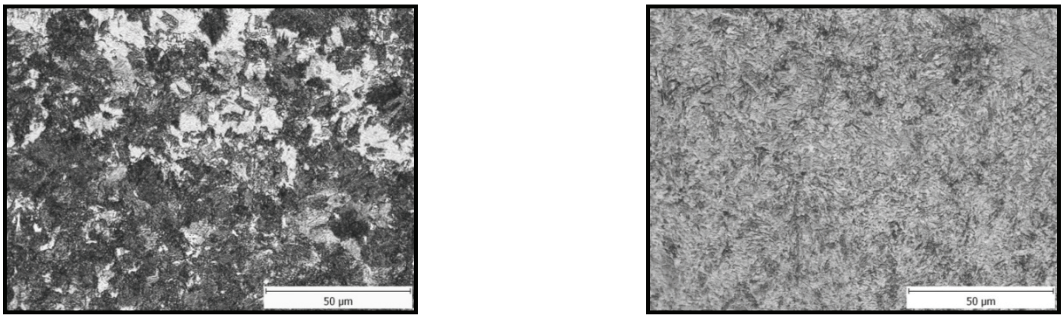


Fig. 8 DCCT diagram of steel 51CrV4 constructed by using the software QTSteel

It is obvious from comparison of **Figs. 7** and **8** that calculated disintegration diagram with influence of deformation is untrustworthy. In comparison with the experiment it again contains a distinct area of ferrite formation, line of martensitic transformation is all the time constant and it does not reflect its real drop. In the case of bainitic and particularly pearlitic transformation this is a principal disagreement from the viewpoint of shape and coordinates.

Optical metallographic analysis was performed in this case as well. Examples of structures of selected cooling rates after dilatometry with influence of preceding deformation are presented in **Fig. 9**, while **Fig. 9a)** shows a micrograph of the sample cooled at the cooling rate of 1.5 °C/s, the structure of which is formed by a mixture of bainite, martensite and pearlite. In **Fig. 9b)** the structure of the sample cooled at the cooling rate of 12 °C/s is formed solely by martensite.



a) cooling rate 1.5 °C/s b) cooling rate 12 °C/s

Fig. 9 Examples of microstructure of the samples subjected to dilatometric tests (with deformation)

3.3. Influence of deformation on transformation diagrams and hardness

For the purposes of transparent comparison of both experimentally obtained disintegration (CCT and DCCT) for the steel 51CrV4 a diagram presented in **Fig. 10** was constructed. A distinct influence of deformation is evident in the case of pearlitic transformation, which is significantly accelerated by deformation and therefore shifted towards shorter times. The curve itself of the start of pearlitic transformation is in the case of DCCT diagram more flat. The start of bainitic transformation due to deformation was slightly shifted towards higher temperatures, and moreover a curve was formed, which delimits the termination of this transformation. Nevertheless, the so called bainitic nose remains at the same position. The curve of the start of martensitic transformation was due to deformation slightly lowered, particularly in the areas of higher cooling rates.

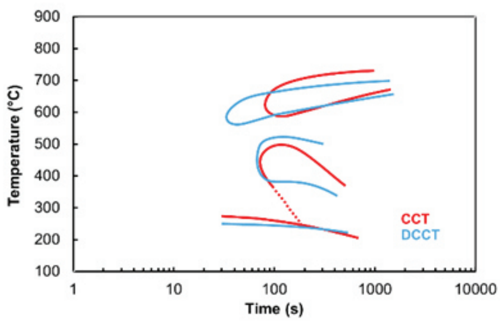


Fig. 10 Comparison of CCT and DCCT disintegration diagrams determined by dilatometry of steel 51CrV4

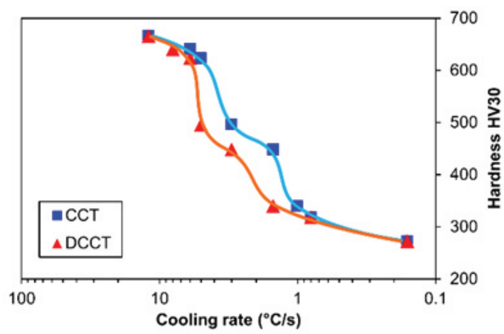


Fig. 11 Effect of cooling rate on the hardness of the samples after dilatometry of steel 51CrV4

All the metallographically analysed samples were also subjected to measurement of hardness according to the Vickers HV30. Graphic illustration of hardness of the steel 51CrV4 as a function of the cooling rate (**Fig. 11**) shows clearly the basic trend, i.e. that hardness decreases proportionately to the cooling rate. The start and end of hardness cures is almost identical, which is given by identical structural composition at those rates. The deviation of the central part of curves is caused exactly by different structural composition and shares of individual components. Certain discontinuity of the course of curves appears at the rates of 1.5 - 3 °C/s (CCT) or 3 - 5 °C/s (DCCT). It is given by an almost leap change of the share of some present structural components.

4. CONCLUSIONS

On the basis of dilatometric tests with heating rate of 1 and 10 °C/s the temperatures of phase transformations of the examined spring steel 51CrV4 were determined and then the temperature of austenitisation suitable for the next tests was determined to be (850 °C). CCT and DCCT diagrams for the steel 51CrV4 were prepared by combination of dilatometric tests, metallographic analyses and measurements of hardness. Thus constructed diagrams were compared with the diagrams calculated numerically by the software QTSteel 3.2. for identical conditions. Experimental construction of DCCT diagram after austenitisation at the temperature of 850 °C evidenced a significant acceleration of pearlitic transformation due to preceding deformation. The start of bainitic transformation due to deformation was slightly shifted towards higher temperatures, and moreover a curve was formed, delimiting the termination of this transformation. Disintegration diagrams CCT and DCCT constructed by computer modelling in the program QTSteel 3.2. showed striking differences in comparison to the diagrams constructed on the basis of dilatometry. It has thus proved a irreplaceability of demanding physical experiments at exact description of kinetics of phase transformations in the course of cooling of specific steel at various cooling rates.

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