INFLUENCING OF TRANSFORMATION KINETIC OF 25CrMo4 STEEL BY THE THERMOMECHANICAL PARAMETERS

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Abstract

The aim of the contribution is creation of transformation diagrams of hypoeutectoid 25CrMo4 steel that is used for tube production for the OCTG (Oil Country Tubular Goods) industry. For a comparison purpose, the CCT diagrams with and even without influence of previous deformation were assembled. In addition, the DCCT diagram (i.e. with previous deformation influence) was exposed to different austenitization conditions. The transformation diagrams were assembled on the basis of dilatometric tests which were confronted with the metallographic analysis and hardness measurement. Due to the influence of previous deformation and different austenitization conditions, peremptory movements of curves in the assembled transformation diagrams were occurred, which, of course, was reflected also on the structure and hardness, respectively. After the previous deformation, the structures of samples had considerably increased share of quenching phases, including of share of acicular ferrite. This, of course, was manifested by increased values of hardness.

Keywords: Transformation diagrams, dilatometric tests, microstructure, deformation

1. INTRODUCTION

The control of thermo-mechanical parameters increases effectiveness of forming of selected types of steel, which are connected with austenite transformations. Nevertheless, the biggest factor is, indisputably, a chemical composition, which, however, we can just slightly influence for the given steel grade in the tolerance limits specified by a standard. A combination of deformation size and chosen temperature of deformation mainly belong to the purposely influenced thermo-mechanical parameters. Conditions of cooling, especially a cooling rate, a size of the austenitic grain and previous deformation, however, play indispensable role with regards to the resulting structure. Transformation diagrams of CCT type (Continuously Cooling Transformation), respectively DCCT (Deformation Continuously Cooling Transformation) serve for mapping these influences in the processes of continuous cooling while considering the influence of deformation of austenite [1-6].

A lot of papers attend to the study of influences of separate parameters such as influence of the size of the austenitic grain or influence of deformation to separate transformations or in general to displacements of all areas in the transformation diagrams themselves. However just a few papers are focused on the endeavor to carry out a complex evaluation how the both parameters influence the kinetics of the products of hypoeutectoid transformations, respectively the resulting structure [5, 7-10].

The subject of this contribution was to compile CCT and DCCT diagrams of steel 25CrMo4, whereas the DCCT diagram of the investigated steel was designed for the specific conditions of austenitization simulating, in some measure, production of seamless pipes.

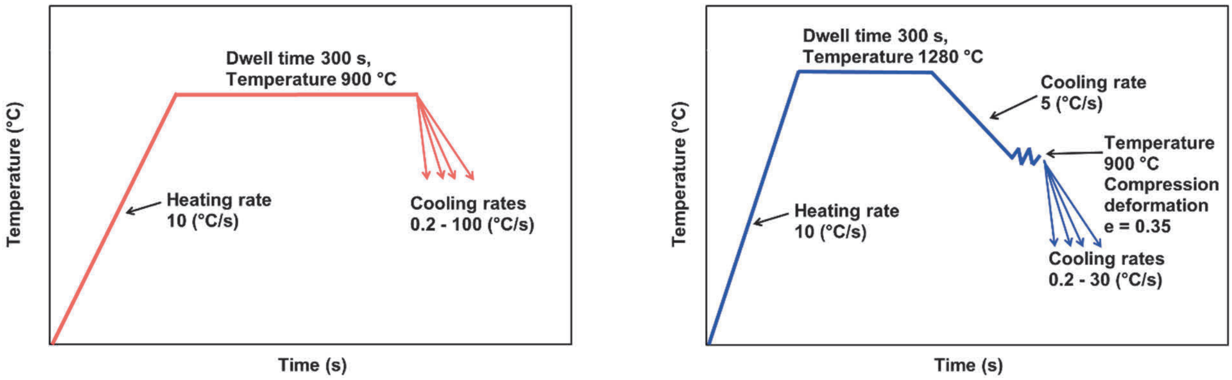
2. EXPERIMENT DESCRIPTION

Steel 25CrMo4 belongs to low-alloyed hypoeutectoid steels and is used for the production of pipe works for the petrochemical industry, parts of machines, vehicles and in the aviation industry [11]. Chemical composition of the investigated steel 25CrMo4 is specified in **Table 1**.

Table 1 Chemical composition of the investigated steel in wt% [11]

C	Mn	Si	P	S	Cr	Mo
0.20 - 0.31	0.56 - 0.94	≥ 0.43	≥ 0.03	≥ 0.04	0.85 - 1.25	0.12 - 0.33

Two sets of specimens were prepared for the purpose of experiment from steel 25CrMo4, namely for the creation of the CCT and DCCT diagram on the basis of combination of the dilatometric tests, metallographical analyses and hardness measurement. The dilatometric tests were realized in the Gleeble 3800 plastometer and its contact dilatometric module. The CCT diagram was compiled after uniform austenitization of the specimens at temperature of 900 °C and consequential fluent cooling in a range of the cooling rate of 0.2 - 100 °C/s. Two-stage heating/cooling was typical for the DCCT diagram, which aimed for the simulation of a thermal procedure of the rolled seamless pipes production by the Mannesmann method. Concretely, specimens for DCCT diagram compiling were heated up to temperature of 1280 °C, where there was a 5-minute rest; the specimens afterwards were cooled with a cooling rate of 5 °C/s to a temperature of 900 °C, where there was a short equalizing 5-second rest and single-axis pressure deformation (logarithmic) with a size of e = 0,35 with a deformation rate of 1/s. The procedure after deformation was the same as in the case of CCT diagram compiling; i.e. fluent cooling with constant cooling rates. All cooling rates were chosen so that it can be possible to describe clearly all important areas of the austenite transformation. Schemes of the courses of the dilatometric tests are specified in **Figure 1**.



mode of dilatometric tests - CCT diagram

mode of dilatometric tests - DCCT diagram

Figure 1 Schemes of the modes of the dilatometric tests for the creation of transformation diagrams from steel 25CrMo4

All dilatometric tests were analyzed with the use of CCT Software. The specimens of the selected cooling rates were put to the metallographical analyses and hardness measurement by Brinell HBW for the purpose of confrontation of the dilatometric tests.

3. DISCUSSION OF RESULTS

The evaluation of the dilatometric tests was performed with the use of a combination of the Newton's method and dilatation curve derivation, whereas the CCT Software is equipped with the both methods. **Figure 2** displays examples of the determined points of transformations for the cooling rates of 0.5, 3 and 100 °C/s, while creating the CCT diagram. **Figure 3** displays the CCT diagram of the investigated steel.

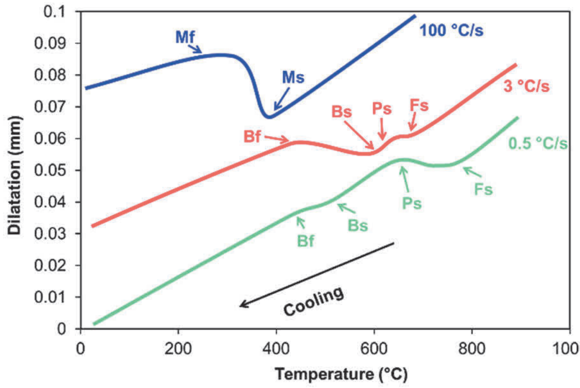


Figure 2 Examples of the determination of the transformation points for the selected cooling rates - CCT diagram

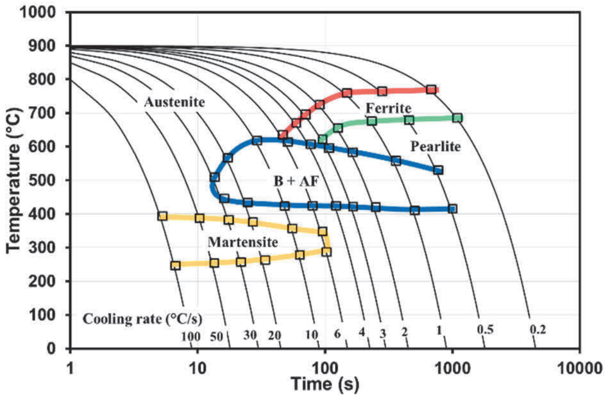
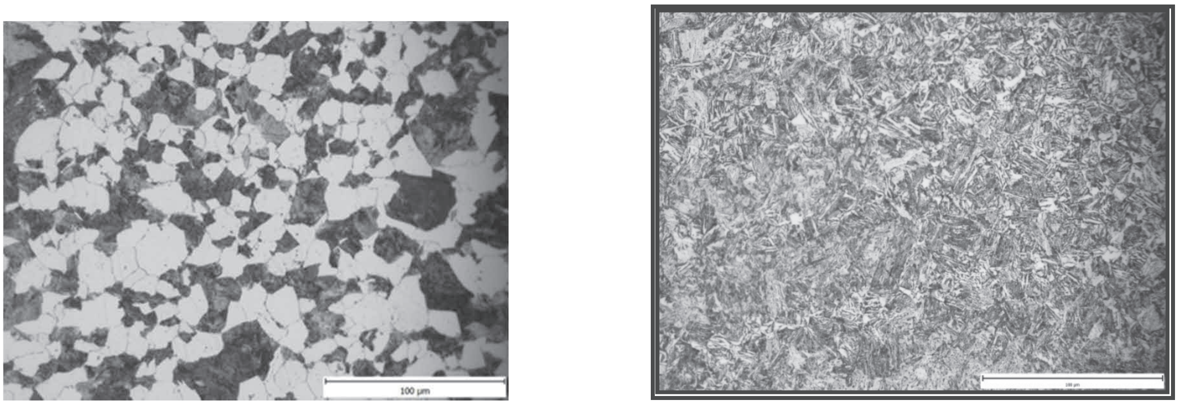


Figure 3 CCT diagram of steel 25CrMo4

As is clear from the CCT diagram shown in **Figure 3**, a relatively wide area is created by bainite, which, as it was confirmed by the metallographical analyses, exists in the mixture with acicular ferrite. A clearly ferritic-pearlitic structure can be expected in the investigated steel at a cooling rate lower than 0.5 °C/s. In the case of an area limiting creation of martensite, it can be seen that the more the cooling rate is decreased, the more the Ms curve is dropped, and on the contrary the more the Mf curve grows. Martensite, in case of this steel, is expected at the cooling rates higher than 6 °C/s. These results, including shares of separate structural ingredients, can also be seen in the shots made after metallographical analyses in **Figure 4**.



Cooling rate - 0.2 °C/s
(F = 56%, P = 44%)

Cooling rate - 6 °C/s
(F = 5%, B+AF = 79%, M = 16%)

Figure 4 Microstructures of specimens cooled with different cooling rates after dilatometric tests without deformation

In case of the cooling rate of 0.2 °C/s, the whole structure is created by polyedric ferrite and pearlite. The specimen cooled with a rate of 6 °C/s consists, first of all, of a mixture of bainite and acicular ferrite with a smaller share of martensite and fine isles of polyedric ferrite in a share that does not exceed 5 %, which is a critical limit for the detection of dilatometry [5].

In case of deformations influenced by the dilatometric tests, a DCCT diagram was compiled - see **Figure 5**. To ensure simpler orientation in the obtained DCCT diagram, and especially to ensure a possibility of a comparison with the CCT diagram, and, thus, for the evaluation of influence of the combination of high-temperature heating and deformation, this diagram must be recompiled to a DCCT diagram, which is initiated by cooling immediately after the finish of the deformation, and, thus, from a temperature of 900 °C. To compile such a diagram, all cooling curves had to be shortened approximately by 81 s (the time for cooling from 1280 °C to 900 °C at a cooling rate of 5 °C/s is 76 s + 5 with a rest at the temperature of 900 °C; the time necessary for deformation was 0.35 s). The values of coordinates of separate transformations has to be also shortened and recalculated by this value. The resulting DCCT diagram after the above-mentioned modifications is shown in **Figure 6**.

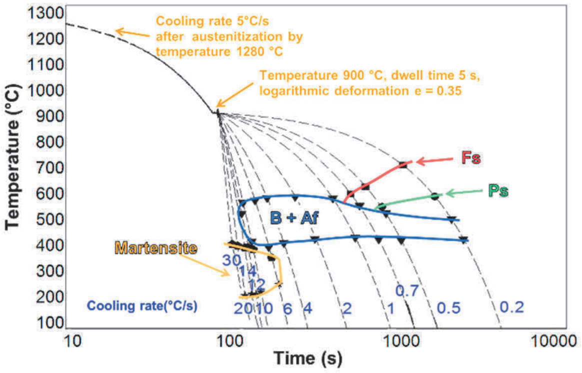


Figure 5 DCCT diagram of steel 25CrMo4 after high-temperature austenitization obtained by means of CCT Software

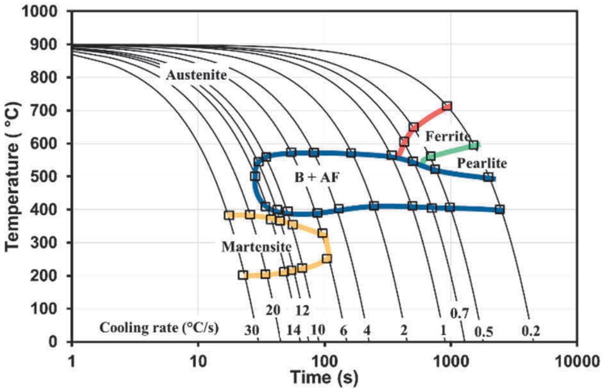
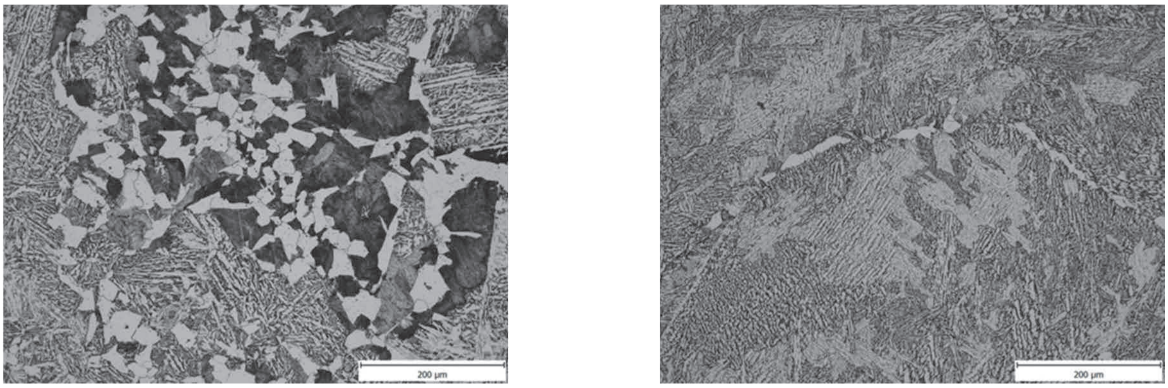


Figure 6 Recalculated DCCT diagram of steel 25CrMo4 with a previous deformation of e = 0,35, obtained on the basis of dilatometric tests after twelve selected cooling rates

As is clear from a photo of microstructures in **Figure 7**, the structure of the specimen cooled with a cooling rate of 0.2 °C/s is practically uniformly represented by shares of ferrite, pearlite and a mixture of bainite with acicular ferrite. It is known that origination of acicular ferrite is connected with the initial coarse-grain austenitic structure, and this our case was similar thanks to the application of high-temperature heating, which supported the growth of the austenitic grain. The structure of the specimen cooled with a rate of 0.7 °C, then, consists of majority share of a mixture of bainite and acicular ferrite with an only minority share of polyedric ferrite, and that is especially at the borders of the original austenitic grains. It clearly shows a mechanism of origination of this structure, when grains of polyedric ferrite are beginning to nucleate at the borders, but the process is advanced by quicker forming on diffusion of independent transformations, concretely, thus, of bainite and acicular ferrite, which are created by similar mechanism [12].



Cooling rate - 0.2 °C/s
(F = 33%, P = 29%, B+AF = 38)

Cooling rate - 0.7 °C/s
(F = 5%, B+AF = 95%)

Figure 7 Microstructures of specimens cooled with different cooling rates after dilatometric tests influenced by high-temperature heating and deformation

A comparative diagram shown in **Figure 8** was compiled for the detection of influence of the combination of high-temperature heating and consequential deformation, which combines both CCT and DCCT variants, and which in the case of DCCT diagram shows its recalculated form. Using this comparison, we will manage, at least partially, to deduce influence of deformation to the position of separate areas in the diagram. Due to the previous deformation and high-temperature austenitization, a positions of separate curves were changed. Relatively decisive changes went on in the curves of ferrite and pearlite, which were displaced in the DCCT diagram in the right direction, i.e. to the area of lower cooling rates. Probably the biggest changes manifested themselves in the area of bainite (a mixture of bainite and acicular ferrite); this area was extended in the DCCT diagram up to the lower cooling rates. Martensite was influenced by deformation and high-temperature heating in a form of increasing Ms.

As is clear from the comparison of hardness for the CCT and DCCT diagrams (**Figure 9**) of the investigated steel, this parameter was also influenced due to the combination of deformation and high-temperature heating. It can be said generally that specimens hardness from the compilation of the DCCT diagram was higher by tens of HBW, which was caused, first of all, by the growth of the structural share of the mixture of bainite and acicular ferrite to the prejudice of a share of polyedric ferrite and pearlite.

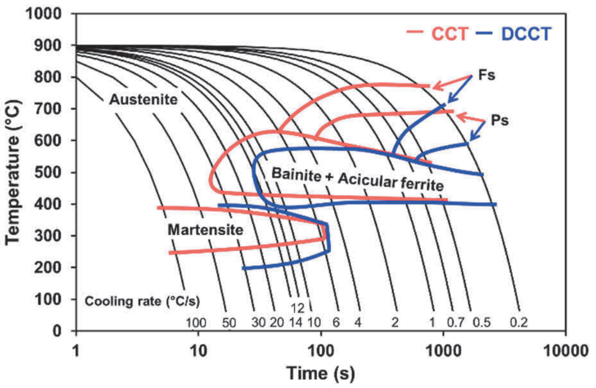


Figure 8 Comparison of CCT and DCCT diagrams of steel 25CrMo4

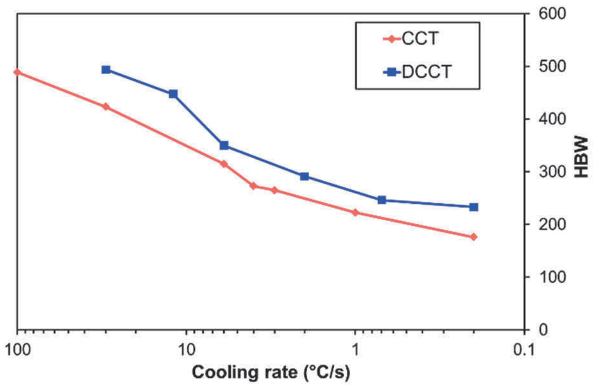


Figure 9 Comparison of influence of a combination of high-temperature heating and deformation to the HBW hardness values

4. CONCLUSIONS

Based on the dilatometric tests, transformation diagrams of CCT and DCCT type of steel 25CrMo4 were compiled. The DCCT diagram was compiled under conditions of high-temperature heating simulating the heating of a semi-finished products before piercing while manufacturing pipes by skew rolling. The transformation diagrams in the both cases were typical by their significant area of creation of a mixture of bainite and acicular ferrite.

By comparing the obtained DCCT diagram with the original CCT diagram, it can be possible to assess influence of the combination of deformation and high-temperature heating to the position and size of separate areas of the transformed phases. Due to the high-temperature heating and previous deformation, Martensite Start temperature was slightly grown. Probably the biggest changes were discovered for the area of bainite (in the mixture with acicular ferrite), which essentially expanded to the zone of the lower cooling rates. The areas of ferrite and pearlite were sidelined to the low cooling rates zone, and temperatures delimiting the start of these transformations of both these phases were relatively significantly decreased. It was, thus, verified that not only deformation but also a size of the austenitic grain, which in the case of two-stage heating had to, for sure, dramatically grow, fundamentally influences the transformation kinetics of all hypoeutectoid products of transformations.

The performed experiment confirmed that physical simulations in the areas of the austenite transformation during cooling continue to be irreplaceable, and that is especially in cases of specific and unconventional modeling, to which our case belongs too.

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