THE ROLE OF INITIAL STRUCTURE ON TRANSFORMATION KINETICS DURING COOLING OF STEEL C10

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Abstract

Transformation kinetics of austenite during cooling is influenced by several factors as chemical content or thermomechanical parameters (temperature, dwell time, deformation, strain rate, cooling rate) and initial structure state, consequently initial austenite grain size. The aim of this article was just to assess the effect of initial structure state (casted, deformed, purposely extremely coarsened) on transformation kinetics of austenite during cooling of steel C10, which was moreover deformed uniaxial compression. This comparison was done on the basis of the construction of three transformation diagrams type DCCT (deformation continuously cooling temperature) for different initial structure state of hypoeutectoid steel C10. DCCT diagrams were constructed on the basis of combination dilatometric tests with an influence previous deformation, metallographic analyses, and measurements of Brinell hardness. For the execution of the experiment, the new optical dilatometric module of the plastometer Gleeble 3800 was used. The experiment demonstrated, that in the case of hypoeutectoid and low alloyed steels and in the case of slowly cooling rate (under 10°C/s) area of ferrite and pearlite formation were not dramatically shifted influence different initial grain size. In the case of higher cooling rate are already evident temperature shifts in areas of ferrite and pearlite. The obtained results show that the finer grain size shifted temperature border area of formation of ferrite and pearlite upward towards higher temperatures. Moreover, in the case of purposely extremely coarsened structure, metallographic analyses showed the formation of acicular ferrite after cooling of cooling rate 35 °C/s.

Keywords: Initial structure, transformation kinetics, transformation diagrams, steel C10

1. INTRODUCTION

The transformation kinetics of austenitic transformation during steel cooling is affected by factors including particularly chemical composition, thermo-mechanical factors and structural state of steel. This issue is most often described by CCT transformation diagrams (Continuously Cooling Transformation) and TTT diagrams (Time Temperature Transformation). CCT diagrams are used for the cases of cooling at continuous rates and they include also the DCCT diagrams (Deformation Continuously Cooling Transformation), which also take into account the effect of the previous deformation, however, only after austenitization. TTT diagrams find their use in the cases of heat treatment followed by isothermal dwell (isothermal annealing) [1-4].

Selected chemical elements contained in steel can shift the transformation diagram in all directions. This is similarly also the case of thermo-mechanical factors, which also influence to a certain extent the position of the curves of individual transformations. A general view of the effect of these parameters on the CCT diagram is shown in **Figure 1**. The assumed influence of magnitude of the initial structure is demonstrated on the low carbon steel CCT diagram in **Figure 2**. It is assumed that in the case of diffusions of controlled austenite transformations during cooling, the area of formation of pearlite and ferrite shifts to higher temperatures with a decreasing size of austenitic grain [3, 5 - 7].

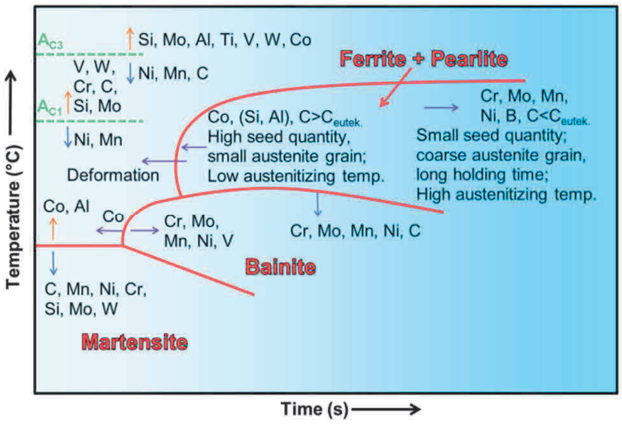


Figure 1 Effect of alloying, thermo-mechanical factors and structure state on transformation kinetics [5]

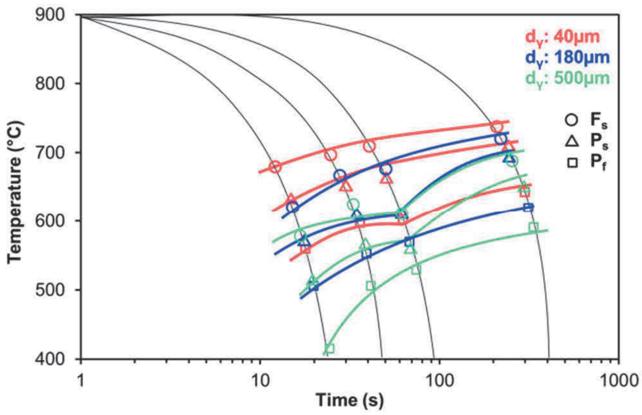


Figure 2 The effect of austenite grain size on transformation kinetics of 0.15%C - 0.5%Si - 1%Mn steels [6]

In this paper, attention was paid to the study of the kinetics of phase transformations considering the effect of deformation and the type of the initial structure (cast vs. formed) of the steel grade C10. Steel grade C10 is suitable for pressed parts and for less loaded machine parts intended for cementing, with less strength in the core after quenching [8].

2. DESCRIPTION OF EXPERIMENT

Transformation diagrams for the steel grade C10 were constructed on the basis of dilatometric tests and they were moreover compared also with the diagrams constructed using the software QTSteel. Dilatometric tests were performed on the opto-dilatometric module of the Gleeble 3800 using the SICO-type samples with a cylindrical shape of 6 mm in diameter and 86 mm in length, the length of the heated zone being 20 mm. The purpose of these tests was to assess the effect of deformation and, above all, the size of the initial structure based on the construction of DCCT diagrams for steel grade C10.

The chemical composition of the investigated steel grade C10 is shown in **Table 1**. The CCT type transformation diagram for the investigated steel is shown **in Figure 3**. The effect of deformation on the transformation kinetics in the case of the investigated steel is documented in **Figure 4**, which shows the CCT and DCCT diagrams, which were calculated with the use of specialized software QTSteel. This simulation confirmed the expected shift of the DCCT diagram in respect to the CCT diagram to the left to shorter times [1,8].

Table 1 Chemical composition of steel grade C10 in wt. % [8]

C	Mn	Si	P	S	Cr	Ni
0.07-0.14	0.35-0.65	0.17-0.36	Max. 0.25	Max. 0.04	Max. 0.15	Max. 0.25

The steel was for the purposes of experiment delivered in two structural states (cast and formed). In the case of the cast structure, these were continuously cast billets, from which the mentioned SICO samples were made from the subsurface areas. The initial austenitic grain size was 62 μm (G = 5). In the case of a formed structure, the samples were made from rolled bars with a diameter of 20 mm with an original austenitic grain size of 22 μm (G = 8).

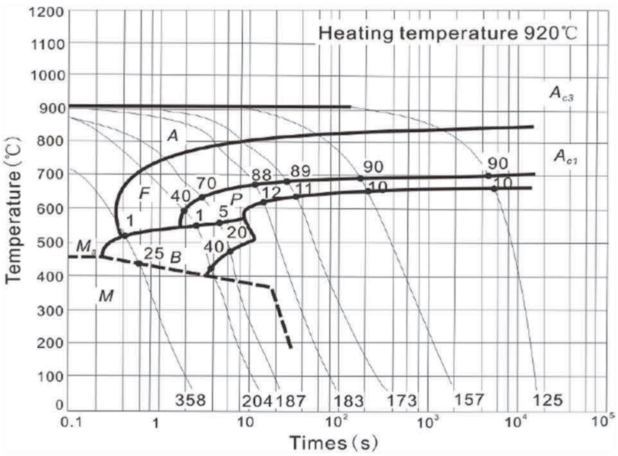


Figure 3 CCT diagram of steel C10 [8]

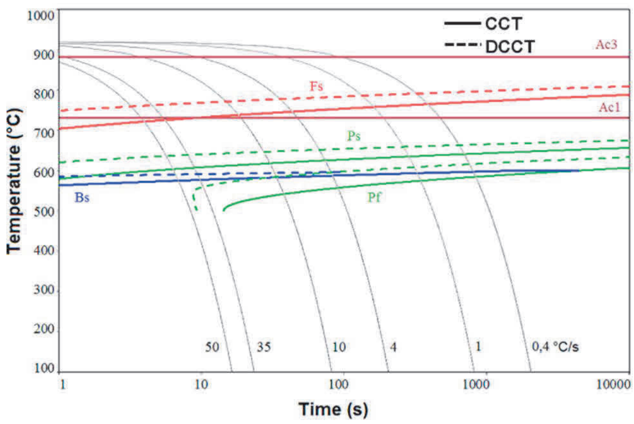


Figure 4 Simulation of deformation effect on transformation kinetics of steel grade C10 - QTSteel

The prepared samples were subjected to heating to an austenitization temperature of 920°C at the rate of 10°C/sec followed by isothermal dwell at this temperature for 120 s followed by deformation of samples by the uniaxial pressure of 0.35 logarithmic strain and at the strain rate of $1s^{-1}$. The samples were after deformation cooled down at constant rates ranging from 0.4 to 50°C/s to room temperature.

For the purpose of comparison, the tests were further expanded by another set of samples, for which efforts were made to produce an extremely artificially coarsened structure. This structure was achieved by a temperature mode, in which samples were austenitized at a temperature of 1100°C with an isothermal dwell of 180 s and then cooled down to 920 °C at cooling rate of 5°C/s; this was followed by equalising dwell at this temperature for 10 seconds, and the samples were then deformed by uniaxial pressure under the same conditions as in the previous cases. The samples were cooled down at the rates of 0.4; 4 and 35°C/s. The samples for these tests were made from rolled bars with homogeneously formed structure.

The samples of all three initial structures with a cooling rate of 0.4 and 35°C/s were moreover subjected to metallographic analyses and measurements of their hardness. The samples for cooling rates of 0.4 and 35°C/s were selected specifically in order to demonstrate the effect of extreme cooling rates on the final structure and hardness values.

3. DISCUSSION OF RESULTS

The DCCT diagram of the steel grade C10 for the initial cast state is shown in **Figure 5**, where it is evident that the structure after cooling at the selected cooling rates will be formed exclusively by ferrite and pearlite. **Figure 6** shows the DCCT diagram for the case of a more sophisticated initial structure. Here too, it can be seen that the diagram is in the investigated area of the cooling rates formed only by ferritic-perlite transformation. **Figure 7** shows the simplified DCCT diagram for the case of complementary tests with artificially formed extremely rough structure. However, for more transparent comparison of all three types (sizes) of the initial structures, a comparative diagram was drawn, which is shown in **Figure 8**. It is clear from this diagram that due to the different size of the initial structures, no principal displacements took place in the direction of the vertical temperature axis. Nevertheless, mild temperature differences occur only at higher cooling rates (35°C/s), where the expected fact is confirmed, namely that due to the larger initial structure, the beginnings and ends of ferrite and pearlite transformations are shifted towards lower temperatures. This phenomenon is due to the higher diffusion rate of diffusion-controlled transformations of coarse-grained materials. In the case of slow cooling rates, this phenomenon is suppressed exactly by a long time between deformation and transformation itself, during which as a result of static recrystallization and undoubtedly also of the chemical composition the structures of steel get unified [2-4].

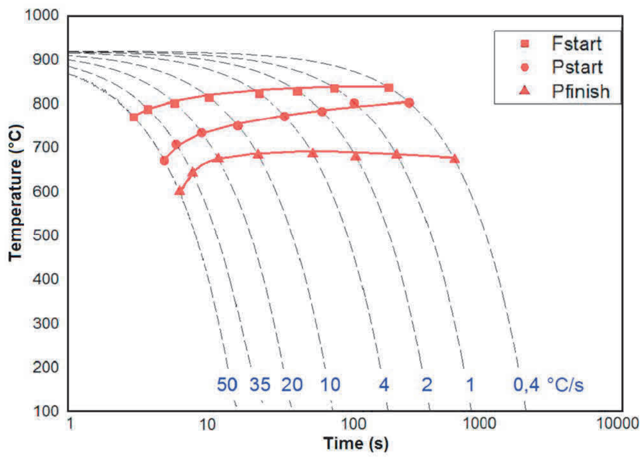


Figure 5 DCCT diagram of steel grade C10 - initial cast state

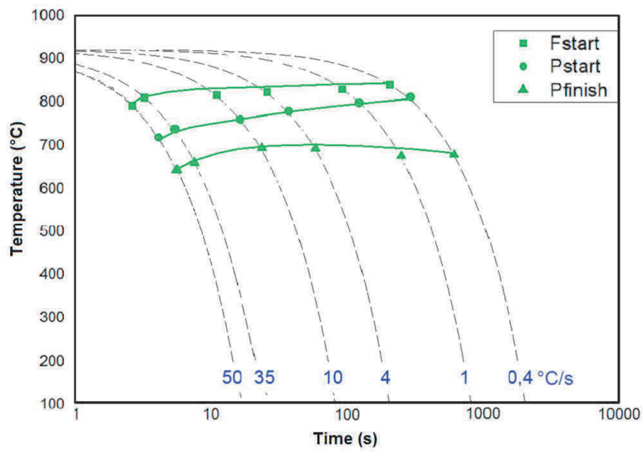


Figure 6 DCCT diagram of steel grade C10 - initial rolled state

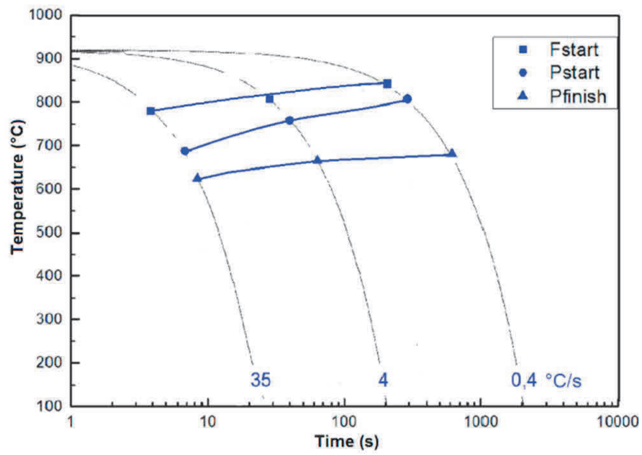


Figure 7 DCCT diagram of steel grade C10 - extremely coarsened state

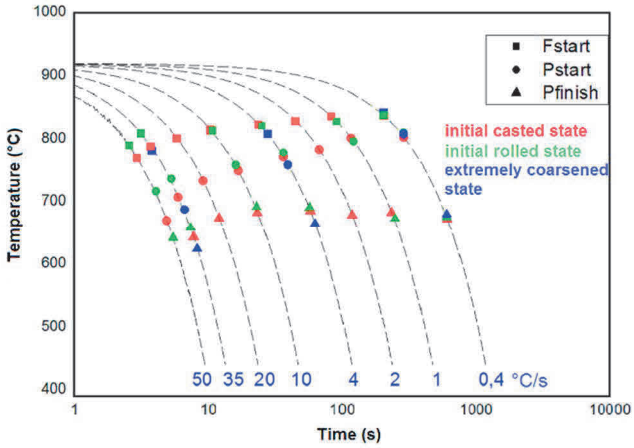
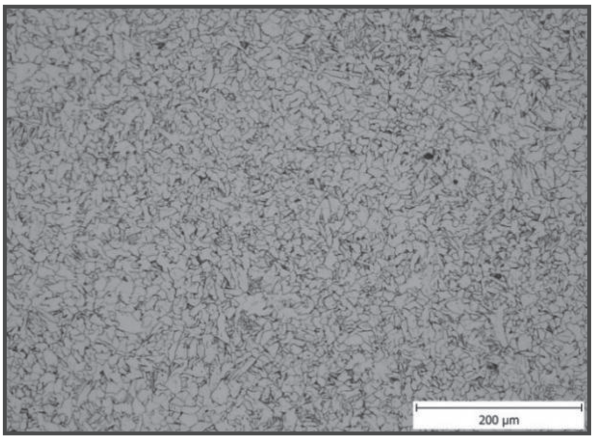
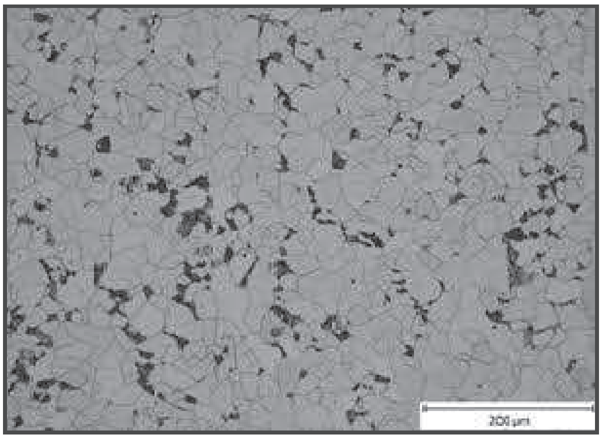


Figure 8 Comparison diagram for all states

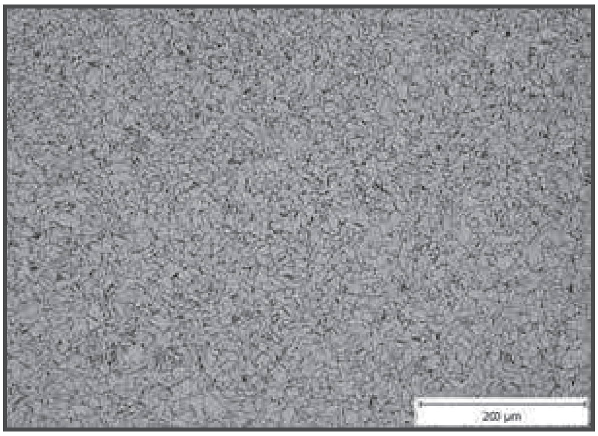
Metallographic analyses confirmed the presence of ferrite and pearlite in the structure of selected samples of the investigated steel in all cases of structural states (**Figure 9**). In addition, the assumption was confirmed that in the case of low carbon and low-alloyed steels, an obvious grain size refinement occurred with the increasing cooling rates [3, 4, 6]. Furthermore, it was found that the combination of high cooling rates and coarse-grained structures results in the formation of acicular ferrite. This trend is most evident in the case of artificially coarsened structure (**Figure 9e**).



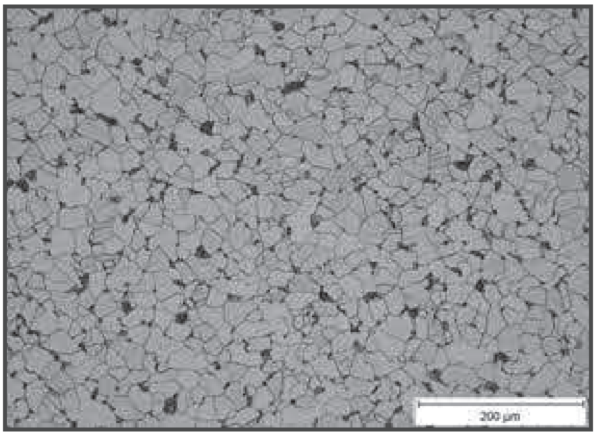
a) initial cast state, cooling rate 35 °C/s



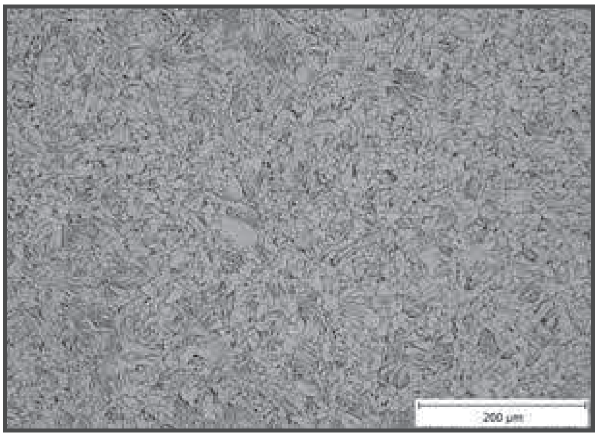
b) initial cast state, cooling rate 0,4 °C/s



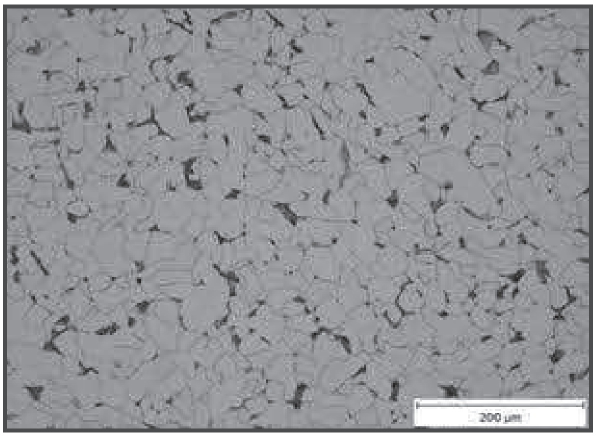
c) initial rolled state, cooling rate 35 °C/s



d) initial rolled state, cooling rate 0,4 °C/s



e) extremely coarsened state, cooling rate 35 °C/s



f) extremely coarsened state, cooling 0,4 °C/s

Figure 9 Results of metallographic analyses of selected samples of steel grade C10

For comparison, the realised physical experiments were compared with modelling in software QTSteel (**Figure 10**) only for the cast and formed state, since only in these cases we were able to enter the value of the initial austenitic grain in this specialised software. By comparing the diagrams in **Figure 8** and **Figure 10**, we can see a fundamental difference, namely that the software QTSteel assumes from the cooling rate of 4°C/s the formation of bainite, which has, however, excluded by the experiment. In addition, overall diagrams calculated in the software QTSteel seem to be shifted toward lower temperatures. **Figure 11** shows the comparison of measured hardness for selected samples after dilatometric tests and, moreover their comparison with QTSteel. Brinell hardness values in the case of dilatometry exactly correspond to metallographic analyzses. In the case of the software QTSteel, the hardness values are higher, especially for the cooling rates of 0.4°C/s, which was caused by a wrong assumption of pearlite formation.

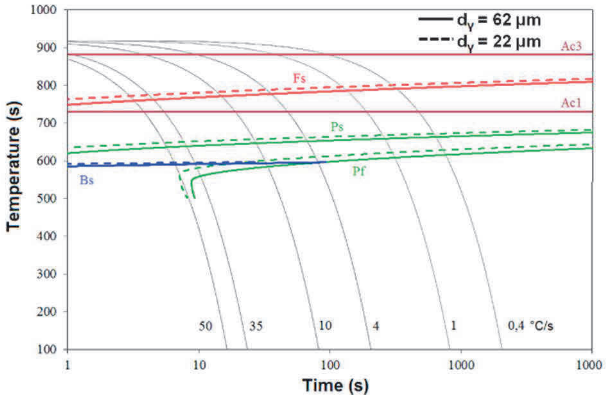


Figure 10 DCCT diagrams of steel grade C10 for initial rolled and cast state - QTSteel

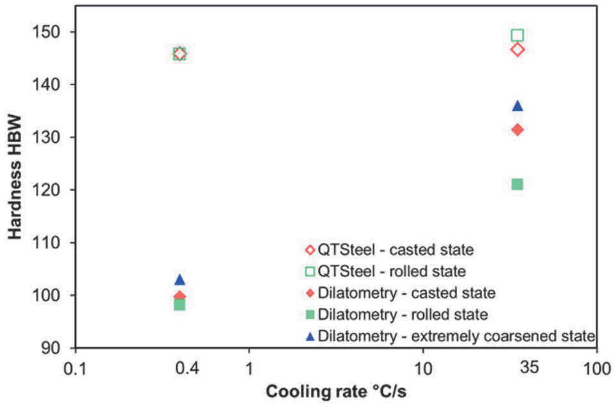


Figure 11 Effect of initial structural state on Brinell Hardness

4. CONCLUSIONS

On the basis of dilatometric tests after deformation of steel grade C10 with three different initial states, the assumption was confirmed that with the decreasing size of the austenitic grain, the transformation temperatures slightly increased in the case of diffusion-controlled transformations (ferrite, pearlite), especially in the case of higher cooling rates of 35°C/s. More pronounced differences were probably achieved in above high-carbon steels and possibly also in high-alloyed steels that were significantly more susceptible to grain coarsening. During the cooling of all samples, the structure was always composed only of ferrite and pearlite, however, in the case of a combination of cast structure and extremely coarsened structure with a cooling rate of 35°C/s, a non-negligible share of acicular ferrite was formed at the expense of massive ferrite. In addition, the influence of the cooling rate on the size of the secondary structure in these low-alloy and low-carbon steels was confirmed. As the cooling rate increases, the structure becomes noticeably refined.

ACKNOWLEDGEMENTS

This paper was created at the Faculty of Metallurgy and Materials Engineering in the Project No. LO1203 "Regional Materials Science and Technology Centre - Feasibility Program" funded by Ministry of Education, Youth and Sports of the Czech Republic; and within the students' grant project SP2017/62 and SP2017/58 supported at the VŠB - TU Ostrava by the Ministry of Education of the Czech Republic.

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