M. KRBAŤA, J. MAJERÍK, I. BARÉNYI, M. ECKERT,
R. ČEP, J. SEDLÁK, I. SAMARDŽIĆ

ISSN 0543-5846
METABK 61(1) 193-196 (2022)
UDC / UDK 536.425:669.26.28.292:536.5:621.56/.59/531.76:620.18=111

DILATOMETRIC ANALYSIS OF COOLING CURVES FOR HIGH STRENGTH STEEL X155CrMoV12

Received – Primljeno: 2021-05-06
Accepted – Prihvaćeno: 2021-08-25
Original Scientific Paper – Izvorni znanstveni rad

The article deals with phase transformations and austenitizing behavior of the X155CrMoV12 tool steel. Dilatation analyses of a series of samples were performed at various cooling rates, chosen in the range from 10 °C/s to 0,1° C/s. Acquired experimental data were used for evaluation of dilatometric curves in order to map the temperature ranges of phase transformations of the austenite to pearlite, bainite or martensite. All experimental samples from dilatometric analyses were then subjected to microstructural analyses and hardness measurements to characterize the microstructure and hardness for each tested heat treatment regime.

Keywords: dilatometry, X155CrMoV12, temperature, cooling rate, martensite

INTRODUCTION

Some currently produced steels with extreme high content of carbide forming elements are known as ledeburitic steels. Ledeburitic structure is typical for white cast irons with carbon content above 2,11 wt. % as is shown in the Fe-Fe_3C metastable binary diagram in Figure 1 [1, 2]. However, alloying element present in the ledeburitic steel extend the area of the ferrite and narrow area of the austenite. Consequently, the eutectoid point S and the point of maximum solubility of carbon in austenite – E are moved to the lower carbon content values. Due to this effect, ledeburite is present in structure of these steels at carbon content below 2,11 wt. %.

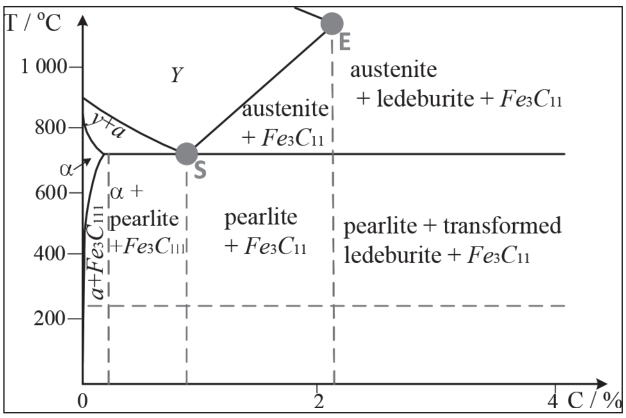

Figure 1 Selected part of phase diagram Fe-Fe_3C binary system

Common carbon content in ledeburitic steels is higher than 0,7 wt. %. At lover carbon content, there would be present a certain amount of δ-ferrite, influencing negatively the hardness [3 - 5].

MATERIALS AND METHODS

The base material used in the performed experiments is the high alloyed tool steel X155CrMoV12 (Table 1) used in engineering industry. It is chromium vanadium steel with high hardenability suitable for quenching in oil and air [6]. The steel is characterized by high wear resistance and very high tensile strength (up to 2 180 MPa) and is mostly used for cutting tools, such as stretching and extruding mandrels, profile blades and complex shaped milling cutters. Its basic mechanical properties can be seen in Table 2.

Table 1 **Chemical composition of the X155CrMoV12 examined steel /wt. %.**

ISO 4967	Min	Max	Spectral analysis
C	1,45	1,60	1,53
Mn	0,20	0,60	0,40
Si	0,10	0,40	0,35
Cr	11,00	13,00	12,00
Mo	0,70	1,00	1,00
V	0,70	1,00	1,00

Table 2 **Basic mechanical properties of the X155CrMoV12 steel**

Mechanical and physical properties	Tensile strength R_m / MPa	Young's modulus E / GPa	Hardness* / HV
	2 180	210	790

*quenched to oil

M. Krbaťa, michal.krbata@tnuni.sk, J. Majerík, jozef.majerík@tnuni.sk, I. Barényi, igor.barenyi@tnuni.sk, M. Eckert, maros.eckert@tnuni.sk, Faculty of Special Technology TnUAD Trenčín, Slovak Republic.
R. Čep, robert.cep@vsb.cz, Faculty of Mechanical Engineering VSB-TU Ostrava, Czech Republic.
J. Sedlák, sedlak@fme.vutbr.cz, Faculty of Mechanical Engineering FSI VUT Brno, Czech Republic.
I. Samardžić, isamardzic@unisb.hr, University of Slavonski Brod, Croatia.

Dilatometry

The DIL805A dilatometer was used to investigate the phase transformations. The device is equipped with a Linear Variable Differential Transformer (LVDT) sensor that measures the changes of sample length during the experiment [7, 8]. The process is carried out in a gas-tight chamber, allowing testing in vacuum (heating phase) or in an inert atmosphere (cooling phase) to minimize the oxidation or decarburization at high temperatures [9, 10]. The temperature is controlled and also scanned by two thermocouples that are spot-welded on the surface of the sample.

The samples were heated up to the austenitizing temperature of 1 030 °C with the rate of 2 °C/s. The hold during austenitizing was 10 min. After austenitizing the samples were cooled with various rates: 0,1; 0,2; 0,5; 1; 3; 5 and 10 °C/s.

As a result of the experiment, seven dilatometric curves were measured where the dilatometric curve represents the length change (ΔL) of the sample with temperature (T). From the heating part of the dilatometric curves, Ac_1 and Ac_3 were evaluated. Cooling part of the dilatometric curves was used for evaluation of the austenite decomposition into to pearlite, bainite or martensite.

The transformation temperatures were determined from dilatometric curves with using tangential extrapolation of linear parts of the curves (ΔL/Lo-T) and its corresponding with first derivative (ΔL/Lo/dt) or second-grade derivative for less noticeable transformation on dilatometric curves. Beside length change curves, the power curves of heating coil (power of coil in percentage vs time) were used for the evaluation. As the sudden power change can be linked to the change of magnetic properties in the sample (e.g. from paramagnetic austenite to feromagnetic ferrite), the curves provided additional information to determine and confirm the transformation temperatures.

RESULTS AND DISCUSSION

Dilatometric analysis

Phase change occurs in the dilatation curve as a step change in length of the experimental sample. For example, critical temperature Ac_1 corresponds with temperature where the sample starts to contract due to the austenite formation in contrast to the linear expansion during heating. Then, the Ac_3 critical temperature is defined as a temperature where the expansion of the sample starts to be linear again. Heating conditions were the same for all experimental samples, therefore the initial and final austenitizing critical temperatures are constant. Their values for X155CrMoV12 steel are Ac_1=820 °C and Ac_3=850 °C and can be seen in Figure 2 and Figure 3.

In Figure 4a., there are visible cooling curve and microstructure of the sample cooled at the rate of 10 °C/s. According to dilatometry, M_s temperature was determined as 260 °C (Figure 4a). This temperature represents a rate when only the martensitic matrix and the excluded carbides appear in the structure.

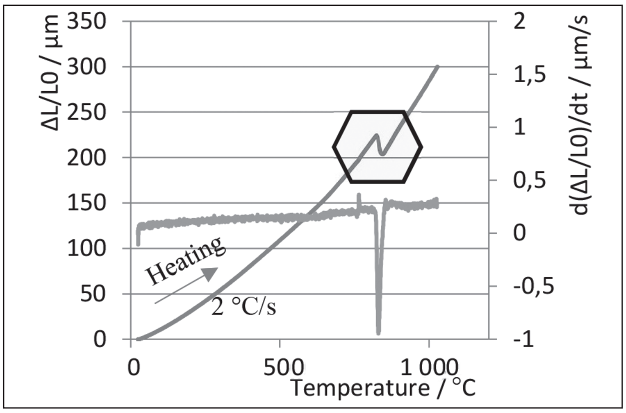

Figure 2 Determination of transition temperatures Ac_1 and Ac_3 with continuous heating at 2 °C/s

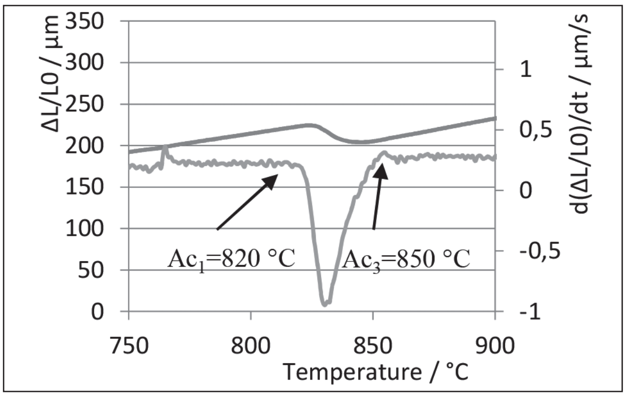

Figure 3 Increase the area of the expansion curve with Ac1 and Ac3

The results for sample cooled with rate of 5 °C/s are shown on Figure 4b. There was observed martensite formation start at 260 °C. In the given curve, the first slight decrease is visible through the derivation, which represents the beginning of the bainite formation immediately followed by the second decrease, which represents the instant formation of the martensite.

Further cooling curve (Figure 4c) represents a cooling rate of 3 °C/s. In the length change curve, two transitions of transformation are visible. The first one began at 290 °C, which indicates the start of bainite formation and the second at 262 °C, which represents the transformation to martensite. From the derivation of the curve, precipitation of carbides is visible at 585 °C.

At a cooling rate of 1 °C/s, the bainite formation started at 340 °C. The martensite formation was shifted to 297 °C (Figure 4d).

Furthermore, a cooling rate of 0,5 °C/s was evaluated (Figure 4e). The beginning of the precipitation of the carbides is visible in the dilatation curve at 689 °C. The bainite formation began at 350 °C and the final transformation to martensite was visible below 250 °C.

The next cooling rate was set to 0,2 °C·s (Figure 4f). The precipitation of the carbides started at 689 °C. Bainite transformation B_s started at 400 °C and the martensite transformation temperature M_s was 300 °C.

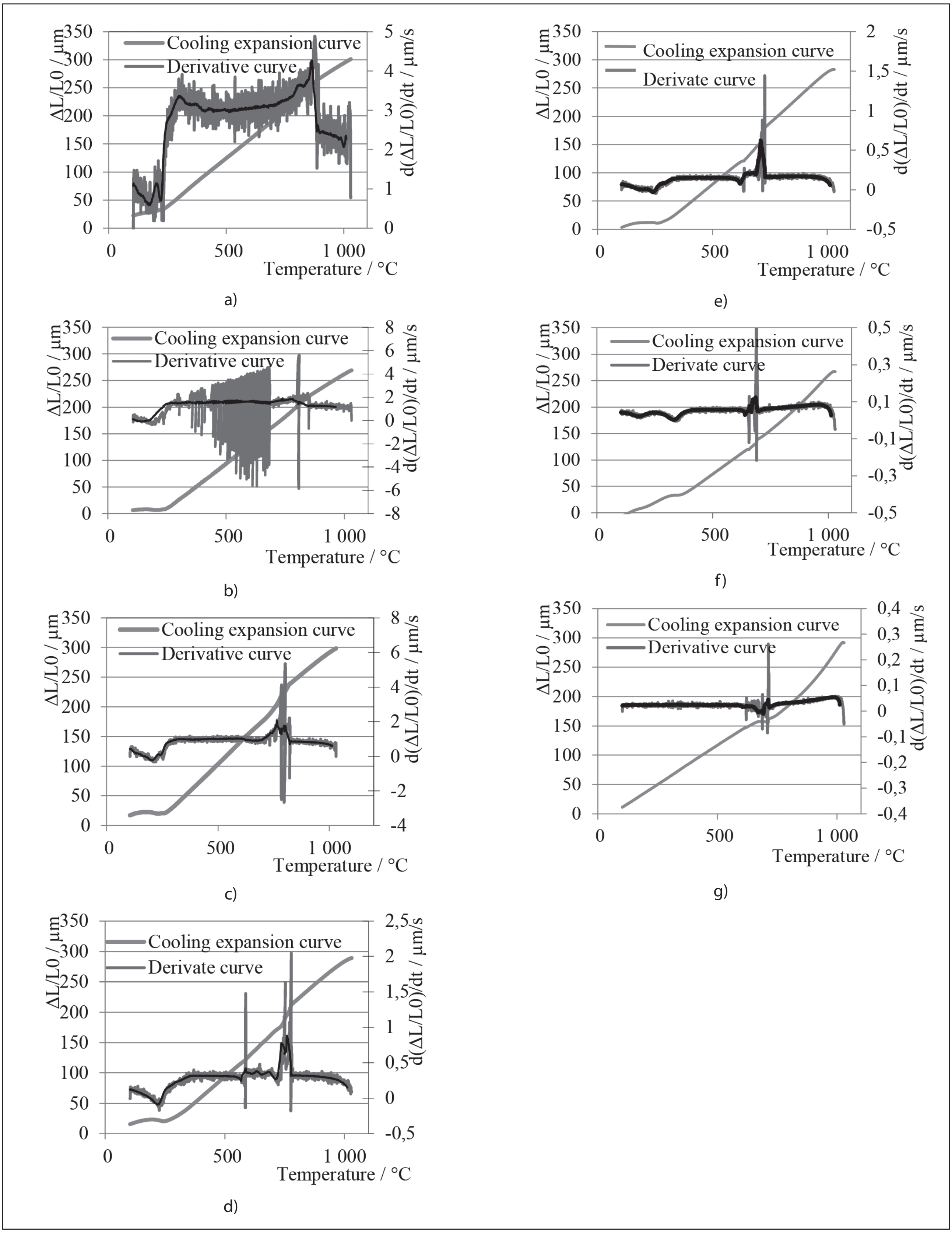

Figure 4 Analysis of the cooling curve, a) 10 °C/s, b) 5°C/s, c) 3°C/s, d) 1°Cs, e) 0,5 °C/s, f) 0,2 °C/s, g) 0,1°C/s.

The results from the lowest cooling rate (0,1 °C/s) are visible in Figure 4g. At the beginning of the cooling, which is the area of the start of the pearlite formation P_s from the austenite. The start of the transformation occurred at 705 °C and its end P_f was at 648 °C. As the dilatation curve continues, a transition through a bainitic transformation begins at a temperature of 430 °C. The transformation to martensite is no longer visible on the dilatometric curve. Therefore, it is possible to predict that the bainitic and martensitic transformation was associated, i.e. the limit value of the transformation to martensite is occurred.

CONCLUSION

The phase transformation kinetics under continuous cooling conditions was examined in detail using dilatometry. The higher percentage of chromium in the material results in the formation of Cr_7C_3 carbide, which results in an increased value of the hardness of the material [11 - 13]. Provided the martensitic transformation is achieved, the resulting critical cooling rate is set at 5 °C/s. This rate, which is precisely bordered by the literature sources, suggests that triple tempering should be followed to achieve the resulting uniform structure of the material. The results of chromium carbides show a fact, that at high cooling rates the incidence of hard carbides is occurred.

Acknowledgement

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-15-0710.

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Note: The responsible person for translation is prof. Martina Šuto, University of Osijek