THE ANALYSIS OF CHOSEN PARAMETERS OF THERMOMECHANICAL ROLLING OF HSLA STEELS

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Abstract

High-strength low-alloy (HSLA) steels are low-carbon steels, making them an excellent construction material for automotive applications, transportation of media such as oil and gas, or responsible marine structures often operating in the harsh weather conditions of northern seas. These steels gain unique properties from micro-additives of Nb, V or Ti (up to 0.15 wt%) and can, for example, reduce the weight of structures by up to 40 % compared with the classic S235JR steel. The only place in Poland where HSLA steel strips can be produced is the ArcelorMittal Poland Hot Rolling Mill in Krakow. These steels are investigated by many research institutes, but due to the restricted number of places where they are produced and the high cost of industrial research, there is still a need for the investigations related to mass-scale production. In this study, the authors examined two selected steels produced at the ArcelorMittal Hot Rolling Mill in Krakow. Dilatometric analyses and strain dilatometry investigations were carried out within this study. The research enabled a good characterization of the material in terms of the phase transformations taking place during controlled cooling as well as the analysis of the material microstructural changes. The obtained results may contribute to more precise control of the material cooling conditions and, consequently, to obtaining the expected mechanical properties meeting customer expectations.

Keywords: HSLA steels, thermomechanical hot rolling, dilatometry, phase transformation, microstructure

1. INTRODUCTION

HSLA-type steels, although known for many years, are invariably popular as a research material for scientists. New research on them is constantly being performed, but most of this research does not go beyond the theoretical or laboratory sphere. This is due to the high cost of research on an industrial scale, but also to the small number of rolling mills capable of producing such steels on an industrial scale [1,2].

Steels of this type are rolled thermomechanically, and it is mainly in one process - hot rolling - that they obtain their unique properties. The process involves heating the material to an austenitizing temperature, which in industrial practice is about 1250 °C. The material is then rolled in several or more passes, where the strip thickness reduction is often as high as 80 % or more. It is important for these steels that the final deformation takes place below the so-called recrystallisation stop temperature (RST), which involves deformation close to the Ar_3 temperature. The deformation is followed by rapid, controlled cooling - the rate affects the desired structure - very often a ferritic-pearlitic structure is expected, which involves a fast, but not excessively fast cooling rate. During controlled cooling, the transformation of austenite to ferrite takes place. In view of the proximity of the RST and Ar_3 temperatures, knowledge of the temperature range of the Ar_3 and Ar_1 transformation is extremely important to design a good thermomechanical rolling process [3-5].

The classic method for determining Ar_1 and Ar_3 temperatures is dilatometry. However, in the literature on micro-alloyed steels, there are several equations that make it possible to calculate these temperatures accurately [6-9]. In this study, the authors analyzed two selected representative HSLA-type steels rolled on a mass scale at ArcelorMittal Poland S.A. Hot Strip Mill in Krakow, Poland, to investigate the extent of the phase transformation from austenite to ferrite during controlled cooling and checked a selection of available equations for calculating the start and end temperatures of the phase transformation.

2. MATERIALS, METHODS AND EXPERIMENT

Two selected representative HSLA-type steels with the compositions given in **Table 1** were analyzed in this study. Specimens with dimensions of 3 x 10 mm were prepared from the investigated steels. The specimens were heated to the temperature of 1250 °C with a heating rate of 2.5 K/s. They were then held at this temperature for 5 min. Samples 1 and 3 were then cooled down to room temperature with a cooling rate of 0.5 K/s - so that a ferritic-pearlitic microstructure was obtained. The next step was to perform dilatometry combined with deformation to check the effect of strain on the phase transformation. Samples 2 and 4 (with the same dimensions as 1 and 3) were heated to the automatizing temperature as samples 1 and 3, followed by a 1 K/s cooling down to 1100 °C and a first strain of 35 %. After deformation, the specimens were cooled to 890 °C with cooling rate of 1 K/s (below the calculated RST) and deformed second time with a strain of 10 % and then slowly cooled down to room temperature with a cooling rate of 0.5 K/s (**Table 2**). The resulting dilatometric curves were analyzed to read Ar_1 and Ar_3 temperatures. Ar_1 and Ar_3 temperatures were then calculated using selected equations from the literature (equations 1 to 9). After dilatometry, samples were also prepared for microstructure studies. The samples were etched with 2 % Nital, after which the microstructures were observed using a Leica metallographic microscope.

Table 1 Chemical composition of the investigated steels

Steel	C_{avg} (wt%)	Mn_{avg} (wt%)	Nb_{avg} (wt%)	Ti_{avg} (wt%)	V_{avg} (wt%)
S1	< 0.07	< 0.90	< 0.04	< 0.01	< 0.01
S2	< 0.08	< 1.00	< 0.06	< 0.04	< 0.01

Table 2 Samples for dilatometric tests

Sample code	Steel	Strain dilatometry
1	S1	No
2	S1	Yes
3	S2	No
4	S2	Yes

Equations used in the analysis:

$$Ar_3 = 914 - 6.85 \cdot CR - 650 \cdot C - 134 \cdot Mn + 179 \cdot Si \tag{1}$$

$$Ar_1 = 814 - 9.08 \cdot CR - 532 \cdot C - 121 \cdot Mn + 165 \cdot Si \tag{2}$$

$$Ar_3 = 903 - 328 \cdot C - 102 \cdot Mn + 116 \cdot Nb - 0.909 \cdot CR \tag{3}$$

$$Ar_3 = 902 - 527 \cdot C - 62 \cdot Mn + 60 \cdot Si \tag{4}$$

$$Ar_3 = 879.4 - 516.1 \cdot C - 65.7 \cdot Mn + 38.01 \cdot Si + 274.7 \cdot P \tag{5}$$

$$Ar_1 = 706.4 - 350.4 \cdot C - 118.2 \cdot Mn \tag{6}$$

$$Ar_3 = 910 - 310 \cdot C - 8 \cdot Mn - 20 \cdot Cu - 15 \cdot Cr - 55 \cdot Ni - 80 \cdot Mo + 0{,}35 \cdot (d - 8) \tag{7}$$

$$Ar_3 = 910 - 273 \cdot C - 74 \cdot Mn - 56 \cdot Ni - 16 \cdot Cr - 9 \cdot Mo - 5 \cdot Cu \quad (8)$$

$$Ar_3 = 910 - 230 \cdot C - 21 \cdot Mn - 15 \cdot Ni + 32 \cdot Mo + 45 \cdot Si + 13 \cdot W + 104 \cdot V \quad (9)$$

where:

CR - cooling rate (K/s)

d - sheet thickness (mm)

C, Mn, Si, Nb, P, Cu, Cr, Ni, Mo - mass fractions of chemical components (wt%)

3. RESULTS AND DISCUSSION

Samples 1 and 3 were subjected to classical dilatometry. **Figures 1** and **2** show the dilatometric curves obtained for the analyzed steels. Ar_1 and Ar_3 temperatures were determined from the curves using the tangent method. For S1 steel, the temperatures were determined as Ar_1 – 625 °C, Ar_3 – 795 °C. For S2 steel, Ar_1 – 640 °C, Ar_3 – 770 °C, respectively. The analyzed microstructures confirmed that a ferritic-pearlitic microstructure was obtained for the samples, similar to this obtained after the mass-scale process.

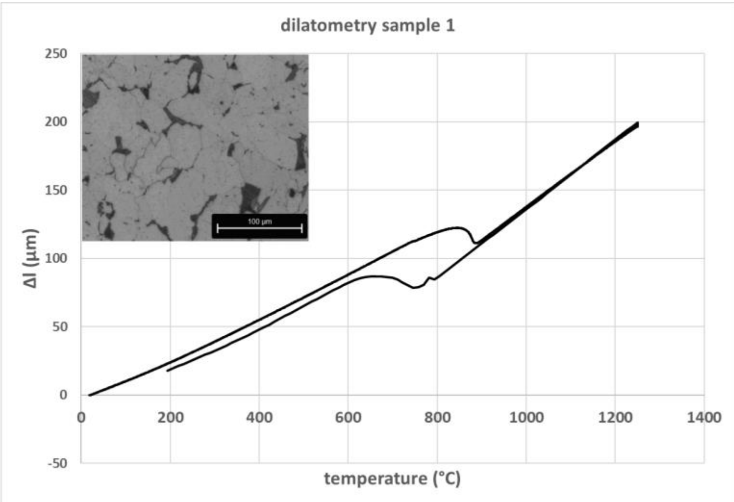

Figure 1 dilatometry curve of sample no. 1

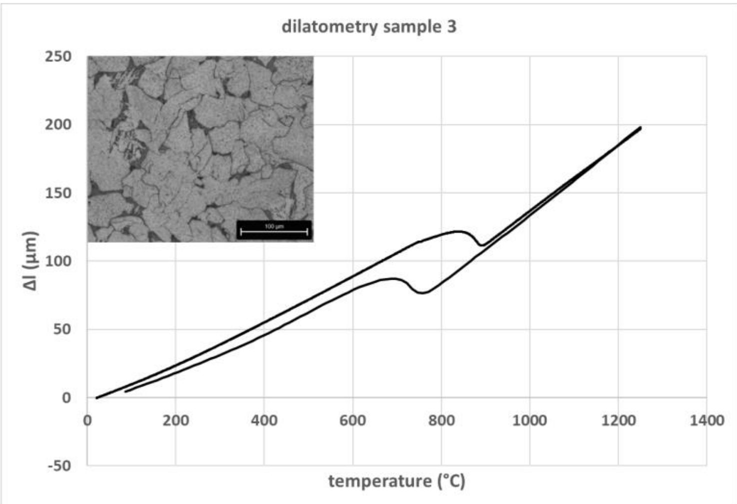

Figure 2 dilatometry curve of sample no. 3

Samples 2 and 4 then underwent dilatometric tests with deformation. The deformation was intended to simulate the actual process - the first rolling in the roughing mill, the second in the finishing mill, below the calculated RST. Ar_1 and Ar_3 temperatures were determined using the same method as commonly used for classic dilatometry. For S1 steel: Ar_1 – 600 °C, Ar_3 – 815 °C, for S2 steel Ar_1 – 620 °C, Ar_3 – 825 °C. For both the analyzed steels, the phase transformation temperature range increased (see **Table 3).**

Table 3 Temperatures of austenite to ferrite transformation

Sample code	Steel	Strain dilatometry	Ar1 (°C)	Ar3 (°C)	Range of transformation (°C)
1	S1	No	625	795	170
2	S1	Yes	600	815	215
3	S2	No	640	770	130
4	S2	Yes	620	825	205

After obtaining Ar_1 and Ar_3 temperatures from dilatometric tests, equations (1 - 9) selected from the literature were checked. The results of the calculations, together with a comparison with the temperatures obtained from the tests, are shown in **Table 4**.

Table 4 Temperatures of austenite to ferrite transformation – obtained from dilatometric tests and calculated

	Dilatometry		calculated (number of equation, temperature in °C)								
Sample code	Ar1 (°C)	Ar3 (°C)	1 - Ar3	2 - Ar1	3 - Ar3	4 - Ar3	5 - Ar3	6 - Ar1	7 - Ar3	8 - Ar3	9 - Ar3
1	625	795	749	667	794	811	788	577	880	824	876
2	600	815	749	667	794	811	788	577	880	824	876
3	640	770	739	659	788	805	782	569	878	819	874
4	620	825	739	659	788	805	782	569	878	819	874

The calculated temperatures based on the selected 9 equations in several cases reflect the temperatures from the process quite well. Unfortunately, none of the equations considers the effect of deformation, which, as can be seen from the results of dilatometric tests, is significant - it will extend the transformation field by 45 °C for S1 steel and by as much as 75 °C for S2 steel. To check the validity of the equations, it is necessary to compare them with the results for dilatometric tests combined with deformation - as this shows the actual process. The calculations for the temperature of Ar_1 are far from those obtained from the tests. In contrast, the Ar_3 temperatures calculated using equations 4 and 8 are quite close to reality.

4. CONSLUSION

Knowing the conditions where the transformation of austenite to ferrite occurs is crucial to designing a good thermomechanical rolling process for HSLA steels. Accurate determination of Ar_1 and Ar_3 temperatures is possible using dilatometry. However, from an industrial point of view, where fast process correction decisions are often needed, the equations calculating these temperatures are equally effective. Knowing the temperature of Ar_3 is much more important than that of Ar_1 - this involves rolling the last passes between just the RST and Ar_3. Hence, basing on the research carried out it can be notices, that the use of equations 4 or 8 in industrial conditions can give a fairly good idea of where the transformation will start.

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