RECRYSTALLIZATION STOP TEMPERATURE AS A CRITICAL ISSUE IN THE DESIGNING THE HSLA STEELS PRODUCTION PROCESS

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Abstract

High-strength, low-alloy (HSLA) steels, although known for years, are not very popular in the industry. Controlled thermo-mechanical rolling poses significant challenges for process engineers and is only feasible in a few rolling mills worldwide. An example is the Krakow Hot Rolling Mill of ArcelorMittal Poland S.A., where such steels can be produced. When designing a process for the production of HSLA steels, it is extremely important to know the temperature at which the recrystallization stops (so called recrystallization stop temperature, RST) - the process should be carried out in such a way that the last passes are already below this temperature, and at the same time care should be taken to ensure that the transformation from austenite to ferrite is close to this temperature - the rolling should take place entirely in the single-phase range. In this study, the authors analysed the current production process in Krakow, Poland, with a view to the occurrence of a recrystallisation stop temperature. The equations available in the literature to calculate the RST were also analysed. The work is an important contribution to improving the design process of HSLA steel production at the Krakow rolling mill.

Keywords: HSLA steels, recrystallization, RST, NRT, thermomechanical rolling

1. INTRODUCTION

High-strength, low-alloy steels (HSLA) have been known for years, but still are the subject of intensive research all over the world. Much of this research, however, remains at the theoretical level, mainly due to the high cost of industrial research and the small number of factories capable of producing this type of steel. The only place in Poland where this type of steel can be produced by hot rolling is the Krakow rolling mill of the ArcelorMittal Poland S.A. group [1,2].

To carry out the thermomechanical rolling process correctly, it is crucial to know and control the critical temperatures. One of such critical temperatures during the hot rolling of HSLA steels is the recrystallisation stop temperature (RST) - temperature at which dynamic recrystallisation processes stop, and non-recrystallisation temperature (NRT) - the temperature below which there is no recrystallisation [3,4]. These temperatures are very important as their influence the final properties of the material. Running the process in such a way, that the final deformation is below RST results in grain refinement and thus an increase in mechanical properties [5].

To determine the RST and NRT, two main approaches are used - an analysis of the actual process from which the magnitude of the forces in the successive passages is derived, converted to the so-called mean flow stress (MFS), and a purely analytical approach by calculating the temperature [6].

In this research, the authors set out to analyse selected HSLA-type steel rolled on an industrial scale at the Krakow Hot Rolling Mill. A series of calculations using the most common RST and NRT equations were carried out and then related to real conditions.

2. MATERIALS, METHODS AND EXPERIMENT

The most produced HSLA steel at the Krakow Hot Rolling Mill was selected for the study. Due to the company's know-how, it was given the working designation S1. The chemical composition of the steel is given in **Table 1** and it was analysed using atomic emission spectroscopy (AES).

Table 1 Chemical composition of the investigated steel

Steel	Cavg (wt%)	Mnavg (wt%)	Nbavg (wt%)	Tiavg (wt%)	Vavg (wt%)
S1	< 0.07	< 0.90	< 0.04	< 0.01	< 0.01

The recrystallisation stop temperature was calculated using the following equations [6]:

$$T_{nr} = [88.1 \cdot \log(\mathrm{Nb} + 0.31Ti + 0.15Al + 1156] \cdot \varepsilon^{-0.12} \cdot \dot{\varepsilon}^{-0.01} \cdot t^{-0.1} \quad (1)$$

$$T_{nr} = 174 \cdot \log\left[\mathrm{Nb} \cdot \left(C + \frac{12}{14}\left(N - \frac{14}{48}Ti\right)\right)\right] + 1444 \quad (2)$$

$$T_{nr} = 887 + 464\mathrm{C} + \left(6445\mathrm{Nb} - 644\sqrt{Nb}\right) + \left(732V - 230\sqrt{V}\right) + 890Ti + 363Al - 357Si \quad (3)$$

$$T_{nr} = 849 - 349\mathrm{C} + 676\sqrt{Nb} + 337V \quad (4)$$

$$T_{nr} = 203 - 310\mathrm{C} + 657\sqrt{Nb} - 149\sqrt{V} + 683e^{-0.36\varepsilon} \quad (5)$$

$$T_{nr} = 893 + 910\mathrm{Nb} \quad (6)$$

$$T_{nr} = 887 + 464\mathrm{C} + \left(6645\mathrm{Nb} - 644\sqrt{Nb}\right) + \left(723V - 230\sqrt{V}\right) + 890Ti + 363A - 357Si \quad (7)$$

$$T_{nr} = 887 + 464\mathrm{C} + \left(6645\mathrm{Nb} - 644\sqrt{Nb}\right) + \left(732V - 230\sqrt{V}\right) + 890Ti + 363A - 357Si \quad (8)$$

Where: Nb, Ti, Al, C, N, V are the chemical elements contents in weight %, ε – strain, $\dot{\varepsilon}$ – strain rate in s^{-1}.

Having calculated the temperature at which the recrystallisation stopped using the above 8 equations, the second part of the experiment began. The forces from the ongoing process were analysed and then converted to the MFS parameter. The MFS is plotted as a function of temperature. According to the literature, the point where the MFS graph breaks down is where the TNR is located - the material starts to strengthen without recrystallising. Finally, the data were correlated with the calculated values.

3. RESULTS AND DISCUSSION

After the selection of representative steel, chemical analyses were performed using atomic emission spectroscopy. With the chemical compositions obtained, it was possible to use the 8 previously presented equations to calculate the temperature at which recrystallisation stopped. The equations were divided into 2 types - equations based on chemical composition only (equations 2, 3, 4, 6, 7, 8) and equations containing the additional effect of strain (1 and 5). shows the results of the calculations. It is known that deformation is extremely important for HSLA steels, so only equations 1 (Fletcher-Bai) and 5 (Bai 1996) can be expected to give more reliable results. The NRTs based on these are 943 °C and 1110 °C respectively.

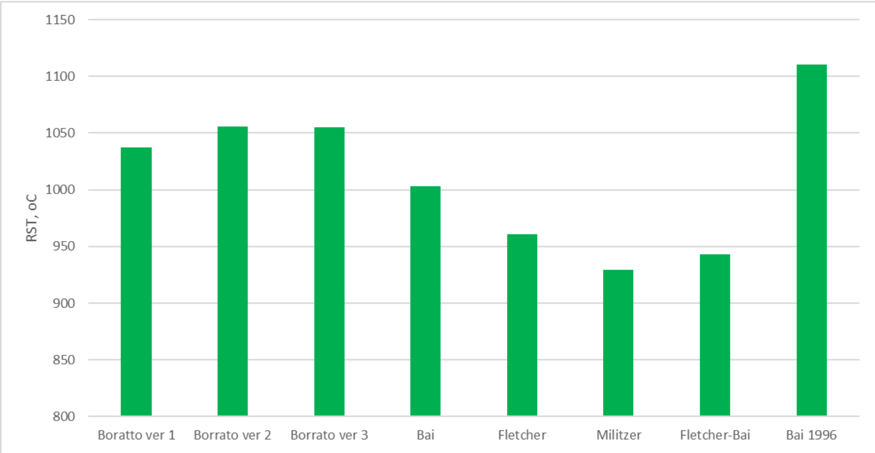

Figure 1 Calculated NRT using different equation

The second part of the research involved process analysis. From the historical data, the average rolling forces needed for each stand of the finishing rolling cage were extracted. The forces were converted to mean flow stress (MFS) and presented as a function of temperature, more precisely as 1000/T in K^{-1}. According to the literature analysis, a curve should be determined which is stable for a certain interval of time and then begins to rise due to the end of recrystallisation. The point of inflection is the point at which the NRT is approximately located. These data are shown in **Figure 2**. From the analysis performed, the NRT field was determined to be at approx. 925 °C which is quite close to Fletcher-Bai equation result.

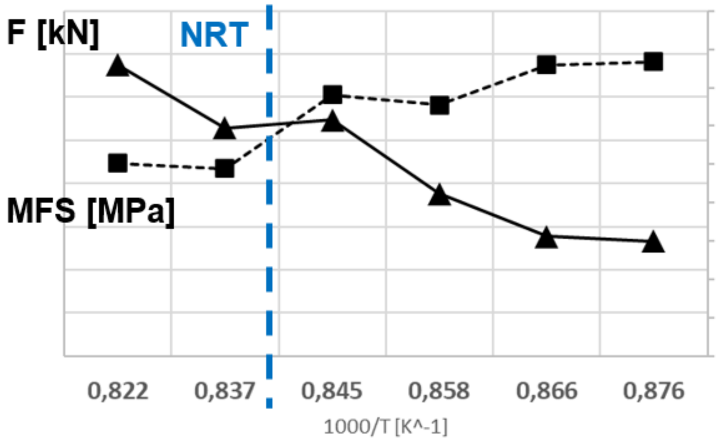

Figure 2 Average rolling forces and converted values to MFS in temperature function. Change in MFS curve shows region where NRT is.

4. CONCLUSION

To summarise the research. The ability to calculate the NRT temperature is extremely important for the design of the production process. The Fletcher-Bai equation gives results very close to the historical process data. The difference of 18 K is acceptable. It can therefore be assumed that the Fletcher-Bai equation can be used for a quick calculation of the NRT temperature for HSLA steel rolled in Krakow Hot Rolling Mill of ArcelorMittal Poland S.A.

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