PHYSICAL SIMULATION OF CONTROLLED ROLLING AND COOLING OF NB-TI MICROALLOYED STEEL STRIP

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Abstract

Reversible two-stand two-high laboratory mill TANDEM was used to study the effect of simulation parameters on the final properties of HSLA steel strip with 0.08 % C, 1.26 % Mn, 0.05 % Ti and 0.03 % Nb. The flat samples were heated at 1230 °C for 20 or 60 minutes and rolled from thickness of 24.0 mm to 3.2 mm by 6 passes. After finishing at approx. 868 °C, three different regimes of cooling were applied: free air cooling only, accelerated water cooling down to 560 °C followed by 1-hour stay in furnace at this temperature (simulating the conditions in industrial strip coil), or water spray cooling followed by free air cooling to room temperature. Ductility of the laboratory rolled products was almost constant. Yield stress and strength was only little influenced by simulation complexity after accelerated cooling, but these values were much lower after simple free air cooling (minus 80 MPa in average). After free air cooling, final equiaxed ferrite grain size was rather greater in the case of longer heating (5.2 vs 4.5 μm), but the microstructure was quite different after accelerated cooling when acicular ferrite occurs and pearlite disappears. The obtained results are important from the point of view of the physical simulation methodology.

Keywords: Tandem, cooling mode, HSLA steel

1. INTRODUCTION

Hot rolling in flat product mills has mainly two functions. The first one is to reduce thickness at high temperatures; the second one is to achieve grain refinement of austenite which will result in appropriate mechanical properties. The geometry quality of rolled strip through thickness reduction is mainly controlled by hot rolling process parameters. Austenite evolution during hot rolling is managed by recrystallization and grain growth, which depend on the parameters such as thickness reduction, rolling speed, mill entry temperature and cooling pattern. Thus, through optimization of the rolling parameters the product quality can be improved, which in turn depends on thermomechanical and metallurgical histories in the strip. On the other hand, the process parameters have a large influence on scale thickness of the strip surface and on roll life [1].

The objective of the work was to investigate material characteristics as yield stress, ductility and others for microalloyed steel. The investigated steel had the chemical composition of 0.075 C - 1.3 Mn - 0.44 Si - 0.032 Nb - 0.047 Ti (in wt. %). The experiment consisted of two different heating modes and three cooling modes. Between this, there was a six pass rolling from thickness of 24 mm to 3.2 mm [2]. The cooling modes were chosen to compare the simulation of cooling in the strip coil with other methods of cooling. The simulation of strip coil was performed by annealing after accelerated cooling with water shower and this was compared with free cooling and accelerated cooling without annealing.

The experiment was intended to simulate the process of rolling and cooling of steel strips on the TŠP 1700 rolling mill in the U. S. Steel Košice [3].

2. EXPERIMENT

Samples were divided in two different heating modes. All samples were heated to the temperature of 1230 °C, first group was inserted to the furnace at 20 °C and then heated for 3 hours to final temperature and then stayed in the furnace for another 1 hour. Second group was inserted into the preheated furnace (970 °C). Heating from of 970 °C to 1230 °C took 50 minutes and after that the samples stayed in the furnace for another 20 minutes.

The rolling had two modes. Both modes were consisted of 6 pass rolling with a difference in delay between second and third pass. One group has a delay approx. of 27 seconds and the other samples had a delay of 17 seconds. The deformations of the samples were 26% for first two passes and 29.5% for the next four passes. This resulted in difference in finishing temperature.

Cooling had three modes. One group of samples was cooled by atmospheric air. Second was cooled with shower to the temperature of 560 °C and then cooled freely on the air. The last group was also cooled by the shower. However, the sample after cooling with shower to the temperature of 560 °C was put into the furnace preheated at 560 °C for an hour.

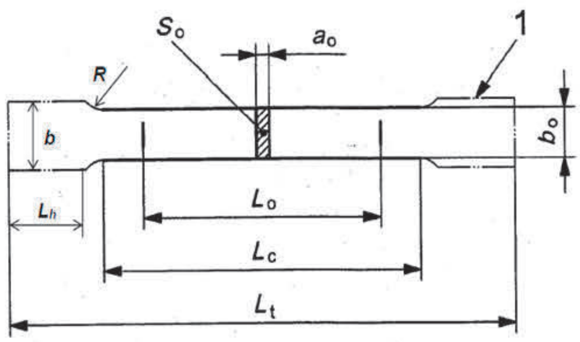
In **Table 1**, there is a schedule of the heating, rolling and cooling, where $\Delta t2\text{-}3$ is the delay between second and third pass, $\Delta t4\text{-}5$ is the delay between fourth and fifth pass and Tf is the finish rolling temperature.

Table 1 Heating and cooling of samples

Sample	Heating (min)	$\Delta t2\text{-}3$ (s)	$\Delta t4\text{-}5$ (s)	Tf (°C)	Cooling mode
L1	20	28.0	10.0	860	air
L3	20	27.0	12.0	862	shower + air
L4	20	25.0	11.0	869	shower + furnace
L12	60	31.0	10.0	867	air
L10	60	28.5	9.5	874	shower + air
L11	60	30.0	9.5	874	shower + furnace
L7	60	17.0	9.0	920	air
L8	60	17.0	11.0	911	shower + air
L9	60	16.5	11.0	926	shower + furnace

3. TENSILE TESTS

Two samples were taken from every rolled and cooled sample for the tensile test. **Figure 1** shows the diameters of the samples, where a_0 is the thickness of the steel strip that it was taken from. The thickness varies around 3.1 and 3.2 mm, depending on the finishing temperature.



a_0 = 3 mm
b_0 = 12.5 ± 0.05 mm
b = 20 mm
L_0 = 50 mm
L_c = 75 mm
R = 20 mm
L_h = min 30 mm
L_t = 160 mm (158 mm)

Figure 1 Dimensions of tensile test samples

Table 2 shows the results of the tensile test of the samples. As we can see, the main difference is caused by the cooling solution and not by the selected heating mode. The ductility results are that the annealing is not beneficent for the material; however the annealed samples had better yield stress values and ultimate tensile strength values. The free air cooled samples had approx. about of 90 MPa lower yield stress than the annealed samples and the non-annealed shower cooled samples had only about of 10 MPa lower yield stress values.

Table 2 Results of the tensile tests

Sample	Ductility (%)	Ultimate tensile strength (MPa)	Yield stress (MPa)
L1	20.0	564	487
L3	20.3	635	547
L4	18.3	625	575
L12	19.1	557	468
L10	20.8	628	543
L11	17.2	621	557
L7	18.6	581	459
L8	14.3	615	548
L9	18.1	626	551

Figure 2 shows the example of the resulting curve of the tensile test that was made after the experiment. There are two lines, because of two tests for each sample. They were taken from different places of the sample, so the results vary a bit.

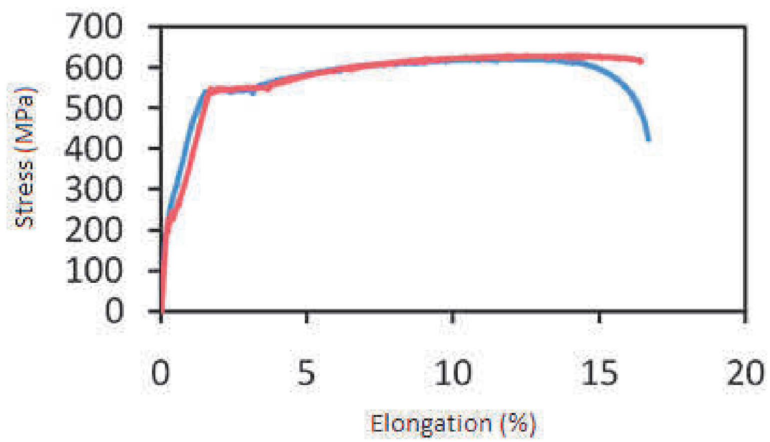


Figure 2 Example of the tensile test for the sample L10

4. MICROSTRUCTURE

There was also a metallographic analysis as a part of the study. Samples that were cooled freely on the air had a structure of equiaxed ferrite and grain size from 4.5 µm to 5.2 µm. The reason of this was the difference in heating mode, were the shorter heating resulted in a smaller grain. Difference between the samples with the same heating and different delay between passes was in the margin of error.

Figures 3, 4 and 5 show the difference in the structures regarding to selected cooling mode. The main difference is between free cooling on the air and accelerated cooling with showers. **Figure 3** shows the sample L1 with the equiaxed ferrite and pearlite. On **Figures 4 and 5** we can see that the accelerated cooling with a shower changed the structure to acicular ferrite.

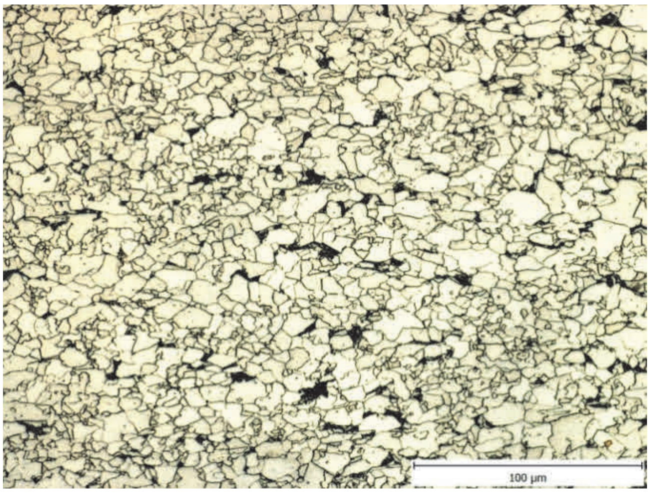


Figure 3 Sample L1 - cooling freely on the air (finishing temperature of 860 °C)

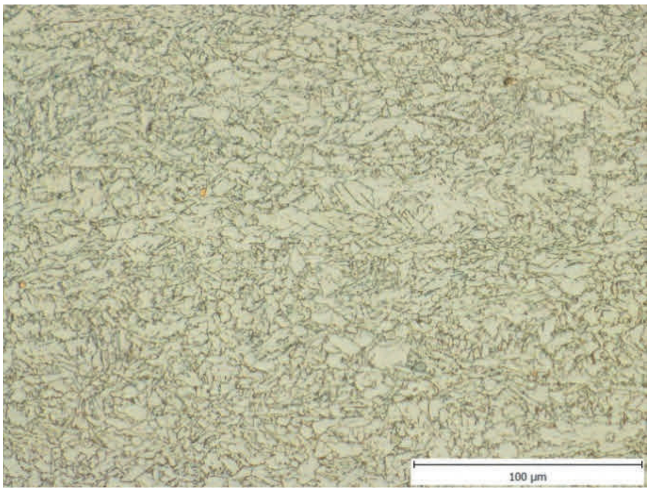


Figure 4 Sample L8 - accelerated cooling with subsequent cooling freely on the air under of 560 °C (finishing temperature of 911 °C)

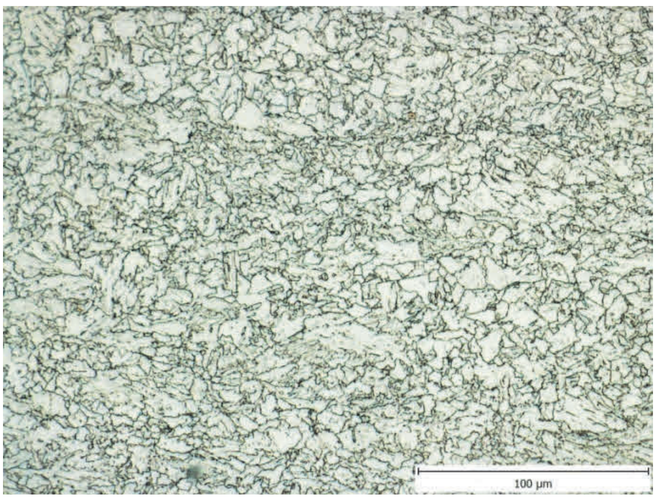


Figure 5 Sample L9 - accelerated cooling with subsequent dwell in the furnace for an hour (finishing temperature of 926 °C)

5. CONCLUSION

- The experiment was intended to simulate the process of rolling and cooling of steel strips on the TŠP 1700 rolling mill in the U. S. Steel Košice.
- This experiment and following tests and evaluation showed us that for this steel, the heating mode does not play a significant role for the mechanical properties.
- The difference was when accelerated cooling was used, however the following annealing does not have significant effect on the microstructure or the mechanical properties. The yield stress was around of 470 MPa for the samples cooled freely on the air and of 545 MPa for the samples with the use of shower and then cooled freely on the air. The samples that were annealed have only around of 10 MPa better yield stresses.
- Ductility was best at the samples that were cooled freely on the air and slightly worse when cooled with shower and air. Lowest ductility was found at the accelerated cooling and annealing mode.
- The possibility to simulate the rolling of steel strips and their cooling was investigated at the TANDEM mill at VŠB-TUO which is equipped with shower cooling mechanism.

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