THE PLASTOMETRIC SIMULATION OF ROLLING OF SEAMLESS TUBES FROM Cr-Mo STEEL

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Abstract

With using of anizothermal plain strain compression tests, which were performed on the Hot Deformation Simulator HDS-20, the physical simulation of rolling and following cooling of seamless tubes from steel 42CrMo4 was performed. The aim was to simulate the thermomechanical conditions during piercing as well as rolling in a pilger mill of the seamless tubes with the final diameter of 273 mm (with the wall thickness of 6.3, 20 and 40 mm) and evaluate the influence of the finish rolling temperatures (chosen in the range from 820 to 970 °C) on microstructural and mechanical properties of the investigated steel. In the case of tubes with the wall thickness of 6.3 and 20 mm the highest hardness was reached at finish rolling temperature of 820 °C and the microstructure of samples was formed by majority share of martenzite and minority share of bainite. In the case of simulation of tube rolling with the wall thickness of 40 mm the chosen finish rolling temperatures did not fundamentally influence the hardness of strained samples and final microstructure of all these samples was formed by the mixture of bainite, ferrite and pearlite.

Keywords: Seamless tubes, plain strain compression tests, microstructure, hardness

1. INTRODUCTION

Constantly growing requirements for mechanical properties of the seamless tubes while preserving the production technologies together with limited possibilities of modification of the chemical composition of the used steels lead to an investigation of the usability of their thermally-controlled rolling. The conditions of controlled rolling are generally known [1-4], but it is not possible to apply them easy to any rolling equipment. Accessible literature contains works resolving influence of selected parameters of controlled rolling on the resulting structure and properties of the seamless tubes [5-7]. Rolling of seamless tubes is a specific method of material hot forming which, in comparison with the classic rolling technologies (for example rolling of strips, rods, wires and so on), requires heating of the input material to very high temperature. The reason is piercing, consequential elongation and calibration of the seamless tube in one heat. By reason of material conveyance, there are relatively long dwell times between these operations, which significantly influence the structure of the rolled tubes. Another specificity of rolling of seamless tubes, which influences their final properties, is their relatively small total strain, respectively a low degree of deforming [8,9].

The Mannesmann method of production of seamless tubes is based on the principle of extrusion piercing with skew rolling, consequential elongation of the perforated half-finished products in a pilger mill and final calibration of the rolled tubes. These method is used for the production of seamless tubes with an external diameter from 60 to 660 mm with a wall thickness of 3 - 125 mm. As an initial material, mostly steel smoothly cast blanks with a circle cross-section are used, but as an alternative, ingots with a circle cross-section can be also applied [10,11].

The aim of the presented paper was to investigate, with the use of laboratory anizothermal interrupted plain strain compression tests, influence of finish rolling temperature on structural and mechanical properties of the seamless tubes from the 42CrMo4 steel with an external diameter of 273 mm with a wall thickness of 6.3, 20 and 40 mm, which are rolled in Třinecké železárny a.s. by the Mannesmann method.

2. EXPERIMENT DESCRIPTION

The anizothermal interrupted plain strain compression tests are mainly used for physical simulation of volume forming processes. Limited material spreading in rigid ends (undeformed areas of the specimen) are used for this type of compression testing [12]. For these tests, respectively simulation, Hot Deformation Simulator HDS-20 can be used, with help of which up to 20 partial deformations (realized in a wide range of strain rates from 0.005 to 100 s^{-1}) can be programmed with precise control of temperature of the tested specimen during its heating, deformation and cooling.

Prismatic specimens with sizes of 10 x 15 x 20 mm were prepared from the investigated steel 42CrMo4 with a chemical composition (in wt. %) of 0.43 C - 0.8 Mn - 1.01 Cr - 0.193 Mo - 0.004 V - 0.001 Ti - 0.002 Nb. These specimens were consequently deformed, respectively locally compressed, by anvils with a width of 5 mm on the Hot Deformation Simulator HDS-20.

By reason of simulation of the whole process of seamless tubes rolling, i.e. including piercing and elongation by the Mannesmann method, all specimens were heated by a electrical resistance heater with a rate of 5 °C·s^{-1} to temperature of 1,290 °C with a dwell time of 5 minutes at this temperature. The specimens were consequently deformed by three pass. The first pass represented deformation at piercing, the second and third ones represented deformation at the pilger mill. The simulation of deformation at the pilger mill was divided in two pass by reason of simulation of the change of temperature of the deformed material under operating conditions of rolling. The specimens were consequently cooled down to temperature of 400 °C. The parameters of deformation (e_h - height strain (-), $\dot{e}$ - strain rate (s^{-1}), $e_{h(total)}$ - total height strain (-)) and final cooling of the specimens during plastometric simulations are shown in **Table 1**. During the inter-pass dwell times, a controlled decline of temperature were proceeding according to the selected temperatures of particular pass - see **Table 2**.

Table 1 Parameters of deformations of individual plastometric simulations

Simulated tube wall thickness	Pass number	e_h	$\dot{e}$	$e_{h(total)}$	Final cooling rate
(mm)	(-)	(-)	(s^{-1})	(-)	(°C·s^{-1})
6.3	1	0.33	4.8	1.77	0.70
	2	0.49	21.8		
	3	0.95	21.8		
20	1	0.28	3.9	1.27	0.44
	2	0.33	12.4		
	3	0.66	12.4		
40	1	0.21	3.1	0.85	0.25
	2	0.22	8.2		
	3	0.42	8.2		

Table 2 Individual pass temperatures

Variants of individual pass temperatures	T1	T2	T3
	(°C)	(°C)	(°C)
1	1,290	900	820
2	1,290	950	870
3	1,290	1,000	920
4	1,290	1,050	970

The inter-pass dwell times were identical for all versions of the simulated wall thicknesses and finish rolling temperatures. The inter-pass dwell time between the first and second reductions lasted 60 sec., respectively the inter-pass dwell times between the second and third pass lasted 10 sec. Temperature *T1*, represented the piercing temperature, was in all cases equaled of 1,290 °C. Temperature *T2* represented temperature of material at the input behind the pilger mill and was chosen in the range from 900 to 1,050 °C. Temperature *T3* represented the finish rolling temperature on the pilger mill and was chosen in the range from 820 to 970 °C.

3. PROCESSING OF MEASURED DATA AND DISCUSSION OF RESULTS

Figure 1 shows dependence of deformation temperatures on deformation resistance of the investigated steel at the plastometric simulation of the rolling of seamless tubes with a wall thickness of 6.3 mm. **Figure 2** represents an example of the dependence of deformation temperatures on deformation resistance of the investigated steel at the anizothermal interrupted plain strain compression tests, performed at the fourth variant of the simulated deformation temperatures (*T2* = 1,050 °C, *T3* = 970 °C).

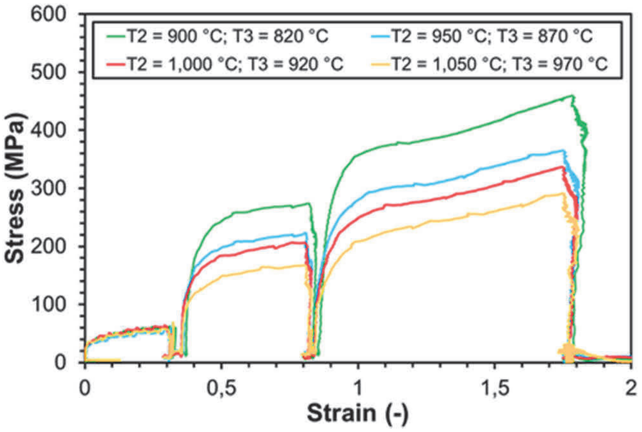


Figure 1 The influence of deformation temperatures on deformation resistance of the investigated steel at simulation of the rolling of tubes with a wall thickness of 6.3 mm

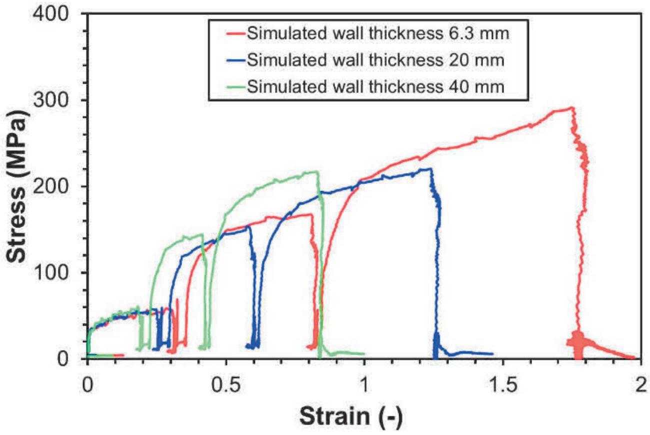
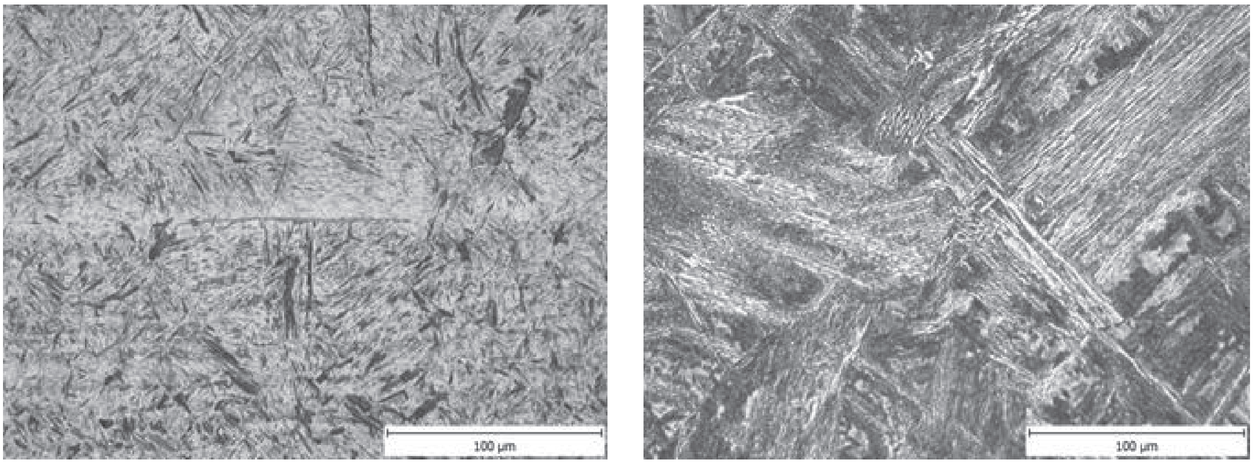


Figure 2 The influence of the strain on deformation resistance at the fourth variant of the simulated deformation temperatures (*T2* = 1,050 °C, *T3* = 970 °C)

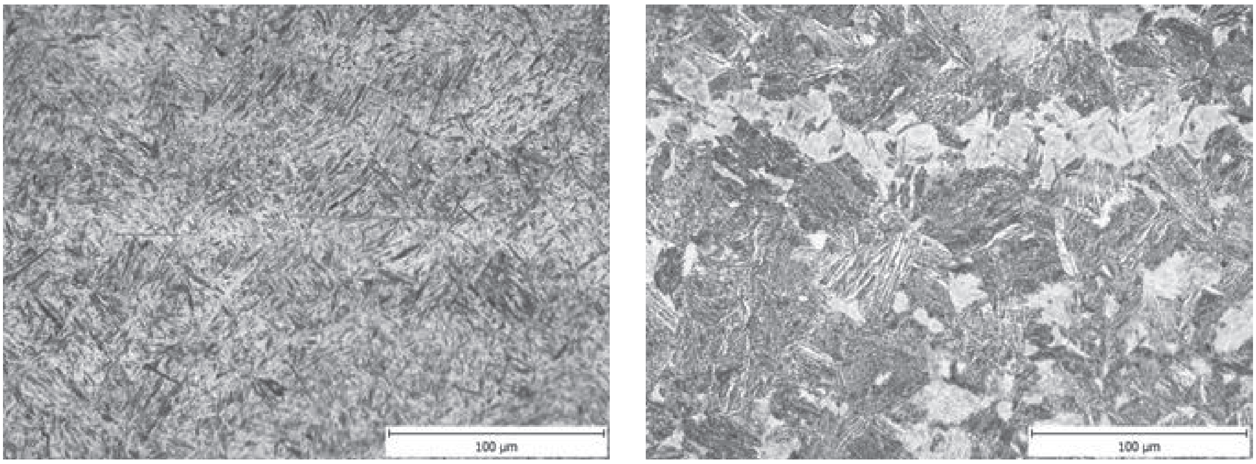
After plastometric simulations, metallographical analysis was performed on all specimens with the use of traditional light microscopy. The deformed part of the specimen was tested in a cross section, in the middle of its length. Photo documentation of the selected specimens microstructure after plastometric simulations is presented in **Figure 3 - Figure 5**. The microstructure of the selected specimens simulating the wall thickness of 6.3 mm is specified in **Figure 3**. At the simulated finish rolling temperature of 820 °C and 870 °C, the microstructure consisted of a mixture of martenzite and bainite. In the case of a specimen deformed at the finish rolling temperature of 820 °C, there was a majority share of martenzite - see **Figure 3a**. The microstructure of the specimens finally deformed at temperature of 920 °C and 970 °C consisted mostly of bainite with a minority share of ferrite. At the simulated finish rolling temperature of 970 °C, bainite was configured in relatively rough blocks - see **Figure 3b**. After intensive final deformation, probably, a quick course of static recrystallization occurred and, evidently, austenitization grain roughen prior to the phase transformation.



a) finish rolling temperature of 820 °C **b)** finish rolling temperature of 970 °C

Figure 3 Microstructure of the specimens after the simulation of the tube wall thickness of 6.3 mm

The microstructure of the specimen simulating the wall thickness of 20 mm and deformed at the finish rolling temperature of 820 °C consisted of the majority share of martenzite with a very small share of bainite - see **Figure 4a**. The microstructure of all remained specimens simulating a wall thickness of 20 mm consisted, mainly, of bainite with a minority share of martenzite and ferrite, whereas martenzite was mainly in segragation bands - see **Figure 4b**.

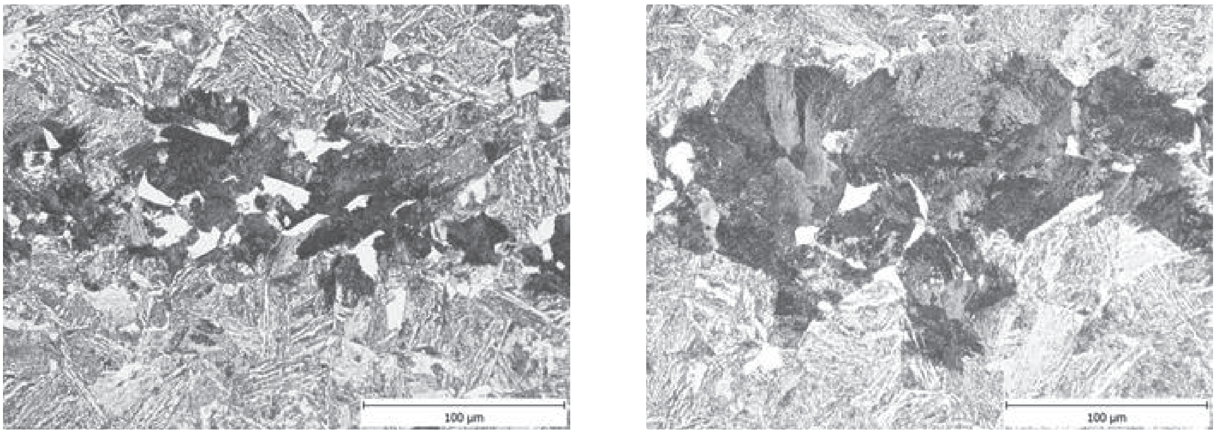


a) finish rolling temperature of 820 °C **b)** finish rolling temperature of 920 °C

Figure 4 Microstructure of the specimens after the simulation of the tube wall thickness of 20 mm

The microstructure of the specimens simulating a wall thickness of 40 mm in all cases consisted of a mixture of bainite, ferrite and pearlite, whereas the bainite share in all cases was majority - see **Figure 5**. The influence of the finish rolling temperature in this case was eliminated by a small final strain and very low cooling rate.

The applied low cooling rates of the deformed specimens led in all cases to the origination of prohibited phases (martenzite and bainite) in the microstructure of the investigated steel, which is in accordance with the transformation diagrams of steel 42CrMo4 presented in papers [13,14].



a) finish rolling temperature of 820 °C **b)** finish rolling temperature of 920 °C

Figure 5 Microstructure of the specimens after the simulation of the tube wall thickness of 40 mm

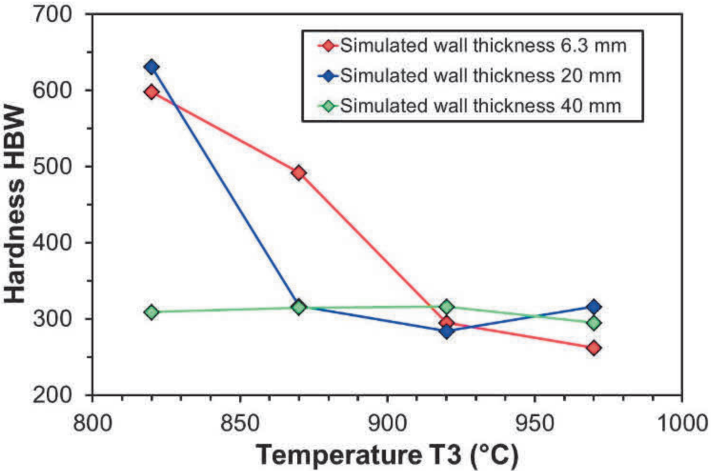


Figure 6 Dependence of hardness on finish rolling temperature

All specimens were after metallographical analyses tested for hardness by Brinell (HBW). The hardness was measured at half of the height of the deformed part of the specimen. A ball with a diameter of 2.5 mm was squeezed into the material with a force of 1839 N, whereas each specimen was tested three-fold and consequently the average value of its hardness was determined. An influence of the simulated finish rolling temperature on hardness of the plastometrically tested specimens is documented in **Figure 6**. The increase of hardness of the investigated steel due to decreasing the finish rolling temperatures was fundamentally evident in the case of the simulated wall thickness of 6.3 mm, respectively in the case of the simulated wall thickness of 20 mm and the finish rolling temperature of 820 °C. Considering dispersion of data in the measurement hardness, it can be stated that the measured values comply with the phase composition of the microstructure of individually deformed specimens.

4. CONCLUSIONS

With using of the anizothermal interrupted plain strain compression tests, there was simply simulated a process of piercing and rolling of the seamless tubes with an extern diameter of 273 mm with a wall thickness of 6.3, 20 and 40 mm for the purpose of investigation of the influence of finish rolling temperatures on mechanical and structural properties of steel 42CrMo4.

From the point of view of hardness increasing, in the case of specimens simulating tubes with a wall thickness of 6.3 and 20 mm, temperature of 820 °C seems to be optimal. In these cases, the microstructure of plastometrically tested specimens consisted mostly of martenzite, which was completed by a minority share of bainite.

The selected finish rolling temperature, however, fundamentally did not influence the microstructure and hardness of the specimens simulating rolling of seamless tubes with a diameter of 273 mm with a wall thickness of 40 mm. By these reasons, it is thus clear that the decrease of the existing finish rolling temperatures in case of tubes with a wall thickness of 40 mm has no sense.

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REFERENCES

[1] TEOH, L. L. Thermo-mechanical processing and microstructure of microalloyed steel bar and wire rod products. *Journal of Materials Processing Technology*. 1995. vol. 48, no. 1-4, pp. 475-485.

[2] MESPLONT, C. Grain refinement and high precipitation hardening by combining microalloying and accelerated cooling. *Revue de Metallurgie - CIT*. 2006. vol. 106, no. 5, pp. 238-246.

[3] VERLINDEN, B., DRIVER, J., SAMAJDAR, I. and DOHERTY, R.D. *Thermo-mechanical processing of metallic materials*. 1st ed. Oxford: Elsevier, 2007. p. 528.

[4] BARANI, A.A., LI, F., ROMANO, P., PONGE, D. and RAABE, D. Design of high-strength steels by microalloying and thermomechanical treatment. *Materias Science and Engineering: A*. 2007. vol. 463, no. 1-2, pp. 138-146.

[5] PUSSEGODA, L.N., YUE, S. and JONAS, J.J. Laboratory simulation of seamless tube piercing and rolling using dynamic recrystallization schedules. *Metallurgical Transactions A*. 1990. vol. 21, no. 153-164.

[6] KAWULOK, P., JURČA, R., SCHINDLER, I., RUSZ, S., TUROŇ, R., OPĚLA, P. and KAWULOK, R. Laboratory Controlled Rolling of Microalloyed Steel for Production of Seamless Tubes. In: *Materials Structure & Micromechanics of Fracture VIII*, Conference Proceedings - Solid State Phenomena, Zurich: Trans Tech Publications Ltd, 2017, vol. 258, pp. 611-614.

[7] WANG, B. and LIAN, J. Effect of microstructure on low-temperature toughness of a low carbon Nb-V-Ti microalloyed pipeline steel. *Materials Science and Engineering: A*. 2014. vol. 592, pp. 50-56.

[8] GULYAYEV, Y.G., MAMUZIC, I., SHYFRIN, Y.I., BURSAK, M. and GARMASHEV, D.Y. Perfection of processes of seamless steel tubes production. *Metalurgija*. 2011. vol. 50, no. 4, pp. 285-288.

[9] WANG, F.J., SHUANG, Y.H., HU, J.H., WANG, Q.H. and SUN, J.CH. Explorative study of tandem skew rolling process for producing seamless steel tubes. *Journal of Materials Processing Technology*. 2014. vol. 214, no 8, pp. 1597-1604.

[10] KOMORI, K. Simulation of Mannesmann piercing process by the three-dimension rigid-plastic finite-element method. *International Journal of Mechanical Scinces*. 2005, vol. 47, no. 12, pp. 1838-1853.

[11] JOUN, M.S., LEE, J., CHO, J.M., JEONG, S.W. and MOON, H.K. Quantitative Study on Mannesmann Effect in Roll Piercing of Hollow Shaft. *Procedia Engineering*. 2014, vol. 81, pp. 197-202.

[12] MANDZIEJ, S.T. Physical simulation of metallurgical processes. *Materiali in tehnologije*. 2010. vol. 44, no. 3, pp. 105-119.

[13] NÜRNBERGER, F., GRYDIN, O., SCHAPER, M., BACH, F.W., KOCZURKIEWICZ, B. and MILENIN, A. Microstructure transformations in tempering steels during continuous cooling from hot forging temperatures. *Steel Research International*. 2010. vol. 81, no. 3, pp. 224-233.

[14] KAWULOK, P., OPĚLA, P., KUBINA, T., SCHINDLER, I., BOŘUTA, J., ČMIEL, K. M., RUSZ, S., LEGERSKI, M. and ŠUMŠAL, V. Deformation behaviour of low-alloy steel 42CrMo4 in hot state. In: *Metal 2011: 20th Anniversary International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2011, pp. 350-356.