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CREDIBILITY OF VARIOUS PLASTOMETRIC METHODS IN SIMULATION OF HOT ROLLING OF THE STEEL ROUND BAR

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Rolling of round bar made of steel 32CrB4 was simulated physically. The interrupted torsion test led to the final microstructure with coarser grains, however, thanks to comparatively large dimensions of the sample this type of experiment was not so sensitive to the cooling rate of the final cooling as compression test. Too high temperature of the end of controlled cooling of the samples after compression test led to partial self-quenching of the investigated material. Decelerated cooling below the temperature of the start of martensitic transformation led in both applied types of compression tests to the parameters of the resulting microstructure and hardness closest to the parameters obtained after laboratory rolling.

Key words: laboratory hot rolling, metallographic analysis, torsion test, compression tests

INTRODUCTION

Simulations, be it mathematical (based most often on the Finite elements method (FEM) [1,2]), or physical simulations are an efficient method for optimization of rolling technologies. It is possible to use for physical simulations the laboratory rolling mills or specialized plastometers [3-7]. Advantage of plastometers consists namely in their greater universality at selection of experimental conditions [8-11]. On the other hand advantage of the laboratory rolling mills consists in the possibility of use of larger samples, which entails possibilities of easier evaluation not only of structural, but also of mechanical properties of the investigated material [12,13].

In December 2012 at the VŠB-TU Ostrava two devices were put into operation, which were unique within the Czech Republic: semi-continuous laboratory mill for rolling of round bars and hot deformation simulator HDS-20 made by the company DSI, equipped with the simulation module Hydrawedge II [14,15]. Both these devices complement suitably the torsion plastometer working in the MMR [16].

The object of our works was comparison of results of physical simulations performed on both plastometers with the results obtained at laboratory rolling of the steel 32CrB4 on the reversible rougher of the semi-continuous mill.

EXPERIMENTAL PROCEDURE

Chemical composition of the steel 32CrB4, which is designated for manufacture of fasteners, was 0,334 C – 0,90 Mn – 0,193 Si – 0,014 P – 0,003 S – 1,21 Cr – 0,0295 Ti – 0,0035 B (in wt. %).

The initial blank of the investigated steel with diameter of 52 mm was austenitized at the temperature of 1 443 K and then rolled by 8 passes to the final diameter of 20 mm. Rolling parameters are summarized in Table 1.

Table 1 **Rolling parameters**

No. of pass	Equivalent strain	Strain rate	Deformation temperature	Interpass time
	/ -	/ s^{-1}	/ K	/ s
1.	0,14	1,8	1 433	
2.	0,24	2,3	1 373	16
3.	0,24	3,0	1 323	12
4.	0,27	3,3	1 273	13
5.	0,26	4,2	1 223	12
6.	0,25	4,3	1 173	14
7.	0,26	5,2	1 128	14
8.	0,26	5,4	1 083	18

The final rolled product was cooled at the average cooling rate of 2,5 $K \cdot s^{-1}$ to the temperature of 873 K, and then cooled at the average cooling rate of 0,7 $K \cdot s^{-1}$ to the temperature of 773 K, which was determined by high-speed temperature scanners LAND.

Torsion simulations of the described rolling process were performed on two types of cylindrical samples. The samples with the deformed part with dimensions Ø 6 × 50 mm are more suitable from the viewpoint of uniformity of strain, however, in their case we achieved 5 times lower strain rate than at laboratory rolling. Shorter samples of the type Ø 6 × 10 mm made it possible to apply identical strain rates as at rolling.

We performed on the simulator HDS-20 the plain strain compression tests (PSCT) on prismatic samples

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with the height of 10 mm, width of 15 mm and length of 20 mm (which are preferentially designated for multi-reduction simulations of forming processes [14,17]), as well as uniaxial compression tests (UACT) with use of cylindrical samples with dimensions Ø 10 × 15 mm (suitable namely for determination of material flow stress [18]). In the first stage of plastometric tests the controlled cooling of the samples was terminated at achievement of the temperature of 773 K.

The laboratory rolled product, as well as plastometrically formed samples were subjected to metallographic analyses. At the testing of HV1 hardness we made always 5 indentures, from the results of which we calculated the average and standard deviation.

DISCUSSION OF RESULTS

Metallographic analyses were performed in the centre of vertical sections of the samples. Microstructure of the laboratory rolled product is documented in Figure 1.

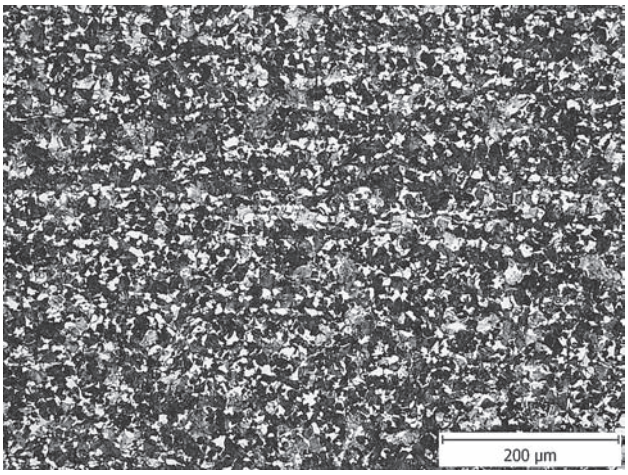
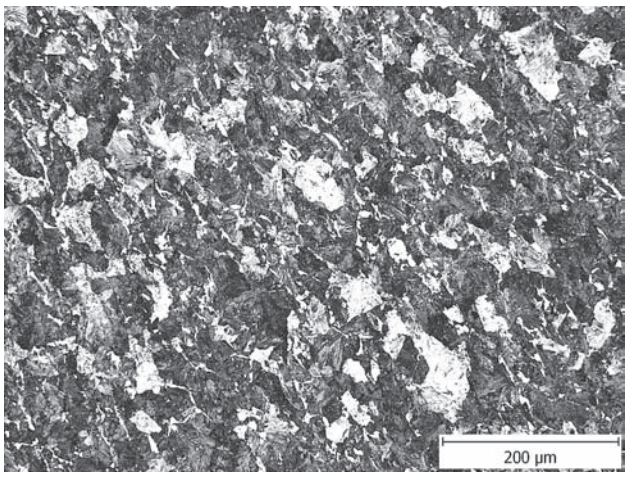


Figure 1 Microstructure of the laboratory rolled product (longitudinal section)

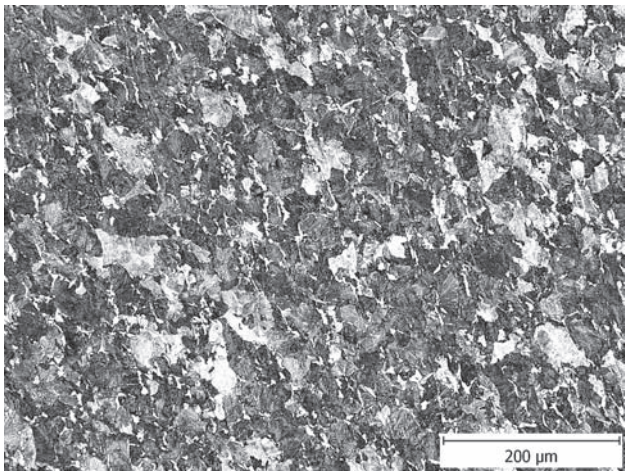
Microstructure of the laboratory rolled product was formed by a mixture of ferrite and pearlite with slightly band arrangement. Islands of bainite occurred sporadically. Average size of pearlitic blocks was approx. 14,5 µm. Laboratory rolled product had an average hardness HV1 = 244 ± 5.

Due to the fact that torsion test is characterized by principal irregularity of strain across the sample cross-section, metallographic analyses were performed at the point of its representative radius, i.e. at the distance of 1 mm below the surface [19]. Microstructure of both twisted samples was formed by a mixture of ferrite and pearlite with minority occurrence of bainite – see Figure 2a), 2b).

We can see on the longer sample greater banding in the direction of twisting. Influence of the applied strain rate on the resulting structure was not significantly manifested, since all reductions were due to their small magnitude connected with the static and not dynamic recrystallization (which can be derived from the shape of the stress-stain curves). This fact was confirmed also by the



a) length of the deformed part of 10 mm



b) length of the deformed part of 50 mm

Figure 2 Microstructure of samples after torsion testing

determined average values of hardness, which were in the case of short sample HV1 = 295 ± 10, and in the case of long sample HV1 = 289 ± 19. Increase in hardness in comparison with the rolled product should be attributed to the occurrence of bainite. On the other hand greater coarseness of the microstructure (mean size of pearlitic blocks was 35 µm in the long sample, and 40 µm in the short sample) reduced relatively the measured hardness.

The samples obtained by compression tests showed microstructure formed predominantly by the mixture of bainite and martensite with minority share of ferrite and pearlite – see Figure 3. In the case of PSCT the hardening components showed banding character. Noticeable occurrence of hardening components influenced fundamentally the hardness values (HV1 = 413 ± 80 after PSCT, or HV1 = 369 ± 60 after UACT), which did not correspond to the hardness of the laboratory rolling product.

The reason of disagreement of structural and mechanical properties of individual samples was the geometry of the samples and cooling conditions after forming. After completion of the torsion test the sample is for certain time still surrounded by a quartz tube and also due to its larger dimensions it cools down relatively slowly, which spontaneously prevented an excessive

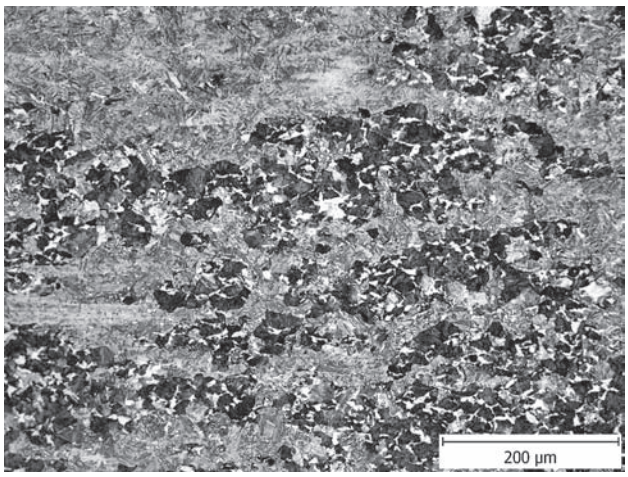


Figure 3 Microstructure of samples after UACT – controlled cooling to the temperature of 773 K

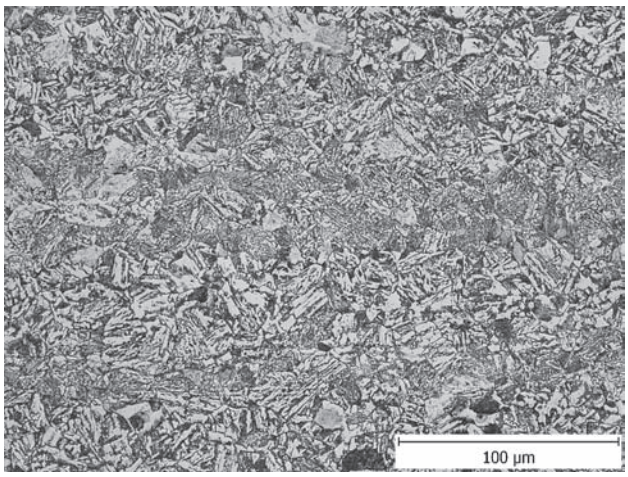
creation of hardening components. In the case of compression tests we obtained samples with the thickness of 1,9 mm (PSCT), or 3,1 mm (UACT), which after completion of the controlled cooling cooled down significantly more quickly. Since it is possible to estimate the martensitic transformation start temperature by calculation in the software QTSteel [20] to be for the given steel 628 K, it is evident that free cooling of the samples below the temperature of 773 K led to partial quenching of material.

For this reason we performed the compression tests again under analogical conditions of forming, but with additional controlled cooling of the samples from the temperature of 773 K down to the temperature of 473 K at the cooling rate of 0,5 $K \cdot s^{-1}$ (determined from the evolution of cooling of the laboratory rolling product), in order to suppress the spontaneous hardening of material. Thus obtained sample after PSCT showed fine-grained microstructure formed by the mixture of ferrite and pearlite with a very specific (non-lamellar) morphology, which was completed by minority occurrence of bainitic bands – see Figure 4a. The resulting hardness of the majority share of microstructure of the sample was HV1 = 282 ± 12, and the mean size of pearlitic blocks was approx. 17 µm.

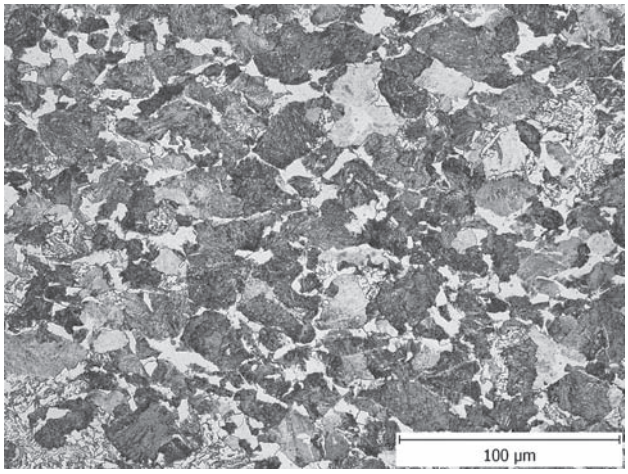
In the case of the sample after UACT we obtained microstructure of similar composition, but with more distinctly distinguishable pearlitic blocks with the mean size of 23 µm – see Figure 4b. Average hardness of this sample was HV1 = 297 ± 21. Microstructure and hardness of the samples obtained by compression tests with comprehensive mode of cooling approached already very close the properties of the laboratory rolling product.

SUMMARY

With use of the selected plastometric methods we simulated hot rolling of round bars from the steel 32CrB4 on reversing stand of the laboratory rolling mill. It was verified that torsion test was for simple simulations of high-temperature forming processes well us-



a) after PSCT



b) after UACT

Figure 4 Microstructure after compression testing – controlled cooling to the temperature of 473 K

able and that it provided resulting mechanical properties of material quite similar to the properties of the relevant rolled product. The resulting microstructure is, however, markedly coarser. Influence of the strain rate (in the model scale of 1:1 or 1:5) on results of the torsion tests was in this specific case negligible, since the controlling structure-forming mechanism during forming was static, and not dynamic recrystallization influenced fundamentally by the strain rate.

It was established that too high temperature of the end of controlled cooling of the samples after compression tests led to partial self-hardening of the investigated material, when very small final thickness of the sample, as well as its too rapid and to some extent irregular cooling played negative role. Decelerated cooling below the martensitic transformation start temperature yielded in both applied types of compression tests to the parameters of resulting microstructure and hardness that were the closest to the given parameters after laboratory rolling.

It was manifested, in the case of the investigated steel 32CrB4, that the cooling mode in its low-temperature stage had fundamental influence on the final properties of the plastometrically formed sample. Larger samples have from this perspective relative advan-

tage at control of the instant cooling rate. It means that for physical simulations and cooling of more bulky long rolled products the test by uniaxial compression is sufficient. Plain strain compression test appears to be more suitable for simulations of the hot rolled flat products and sections with smaller thickness [21], when only this test can generate a band arranged structure analogically to the longitudinal rolling.

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Note: The responsible translator for English language is B. Škandera, Dobrá, Czech Republic