Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 93 **2016**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2016.93.15

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Vakulenko, I., Bolotova, D., Perkov, O., Lisniak, A. Influence of hot-reduction parameters on the steel austenite structure of a railway wheel. *Scientific Journal of Silesian University of Technology. Series Transport*. 2016, **93**, 141-148. ISSN: 0209-3324.
DOI: https://doi.org/10.20858/sjsutst.2016.93.15.

Igor VAKULENKO[1], Dariy BOLOTOVA[2], Oleg PERKOV[3], Alex LISNIAK[4]

INFLUENCE OF HOT-REDUCTION PARAMETERS ON THE STEEL AUSTENITE STRUCTURE OF A RAILWAY WHEEL

Summary. The formation of grain structures with boundaries similar to substructures is one of the factors contributing to grain refinement in hot-reduction carbon steel. At the forming of a rim, the slight cooling-down (100-150°C) of the surface volumes is sufficient to increase their strength characteristics. After that, an increase in the magnitude of the hot-hardening of metal in the central rim volumes will lead to the formation of a more uniform fine-grain austenite structure over the rim section.
Keywords: rim railway wheel, grain size, austenite, temperature, hot-hardening

1. INTRODUCTION

In the process of manufacturing railway wheels, the sequential reduction of blanks in the roll passes of rolling mill pressure equipment at a temperatures of 1,200-1,250°C is accompanied

[1] Academician V. Lazaryan Dnipropetrovsk National University, Lazaryan Str. 2, Dnipropetrovsk, Ukraine. Email: dnyzt_texmat@ukr.net.
[2] Dnipropetrovsk Professional Railway Lyceum, Universal Lane 7a, Dnipropetrovsk, Ukraine. Email: dnyzt_texmat@ukr.net.
[3] Z. I. Nekrasova Iron and Steel Institute, NAN Ukraine, Starodubov Sq. 1, Dnipropetrovsk, Ukraine. Email: dnuzt_texmat@ukr.net.
[4] Dnipropetrovsk National Mountain University, K. Marks Av. 19, Dnipropetrovsk, Ukraine. Email: aleklisn@gmail.com.

by the formation of considerable structural heterogeneity of carbon steel. The observed phenomenon is caused by the high temperatures of metal reduction, the intricacy of forms and the different thickness of some elements of the railway wheel. Microstructural studies [1,2] have established that, in the central volumes of the wheel rim, the degree of plastic deformation does not exceed 10%, while it reaches 50-60% near the tread area. Differences in the degree of plastic deformation at the above-mentioned temperatures of reduction have a certain influence on the development of austenite recrystallization processes. On the basis of the data in [3], at a constant temperature of heating, proportional to the degree of plastic deformation above the critical value (according to different estimates from 6-10% [4,5]), the austenite grain size decreases. On this basis, the austenite grain size in the central volumes of the wheel rim, after the termination of hot-reduction and when separate heating is necessary for thermal hardening with tempering, is approximately 0 or 1 point, and near to the tread area is not more than 2-3 points on the scale of the State Standard 5639 [1]. The formed inequigranular structure of austenite over the rim section after hot-rolling is inherited by the metal structure after the final heat treatment of the wheel, resulting in a corresponding change in the property complex.

Reduction in the inequigranular austenitic structure over the rolling section can be achieved by using controlled rolling technology [4,5]. The implementation of this technology in practice is based on a certain decrease in temperature of hot-reduction in the process of rolling production. On this basis, as a result of the rolling cool-down, the colder metal volumes, having increased hardness, will be less subject to deformation at the subsequent reductions, with more heated internal volumes being able to be reduced by a larger amount. Taking into account the above-mentioned observations, one should expect an increase in the degree of metal reduction in the axial volumes of rolling with large cross sections.

1. PURPOSE OF WORK

The article seeks to estimate the influence of the value and temperature of hot-reduction on austenite grain size while rolling the rim of a railway wheel.

2. MATERIALS AND RESEARCH METHOD

Rim fragments of railway wheels with a carbon content of 0.55 and 0.65% C with chemical elements within the grade composition of steel 60, according to the State Standard 9036, were the material for this research. The blanks in the form of the plates with dimensions 70×120 mm were cut out of the wheel rim, with the thickness adjusted so that, after reduction to the required value of deformation, it was 15 mm. Before heating for rolling, the plates were subjected to normalization. Hot-reduction was performed under the conditions of the DUO 180 type rolling mill, at the deformation rate of 0.3 m/s in one pass with subsequent accelerated cooling. The temperature range of hot-deformation was 950-1,150°C, at a 10-50% degree of reduction in thickness. The minimum temperature of the hot-reduction was limited by the structural strength of the rolling mill equipment. The microstructure was studied under the Epiquant light microscope with a magnification x100. In order to prevent the austenite grain growth after the hot-reduction termination, the samples were subjected to accelerated cooling in water. Austenite grains were detected using the etchant solution picric acid in water, with the size determined using the methodology of quantitative metallography [6].

3. DISCUSSION OF THE RESULTS

Microstructure analysis (Fig. 1) of the steel samples with a carbon content of 0.55% C after the 10% reduction in the temperature of 950°C revealed the formation of an austenite structure in the form of grains close to the polyhedral one with an average size (d) of about 50-60 μ. With regard to the deformation temperature of 1,100°C, the formation of a significant inequigranular structure was observed along with an increase in the average grain size (Fig. 1b). The presence of grains with significantly different sizes in the metal structure can be considered as evidence of the recrystallization development by the grain coalescence mechanism [4]. At the same time, an increase in the number of grain boundaries with missing fragments (1b) in the metal structure was discovered. This phenomenon indicates the beginning of abnormal grain growth, which in turn causes an increase in the inequigranular austenite structure [7,8]. Similar metal volumes (with missing boundary sections) were also found in the structure at lower temperatures of reduction (Fig. 1a), although in fewer numbers.

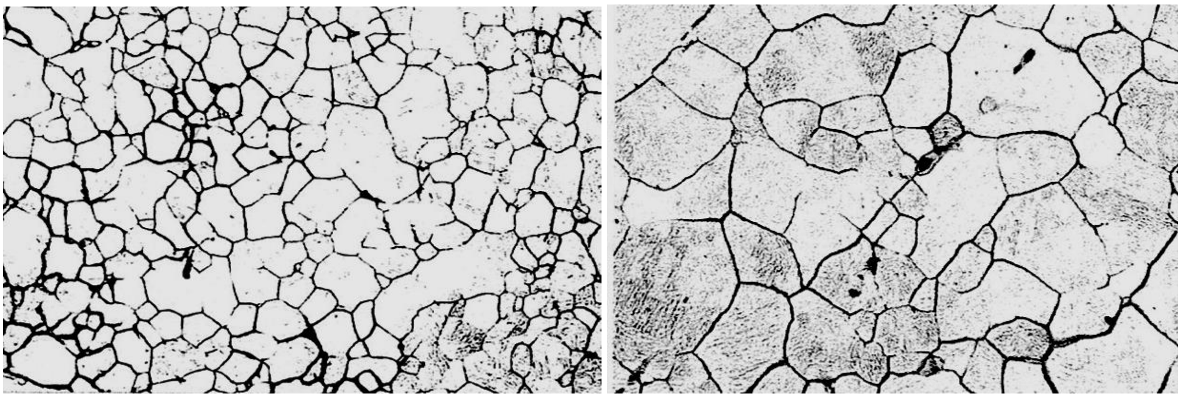

(a) (b)

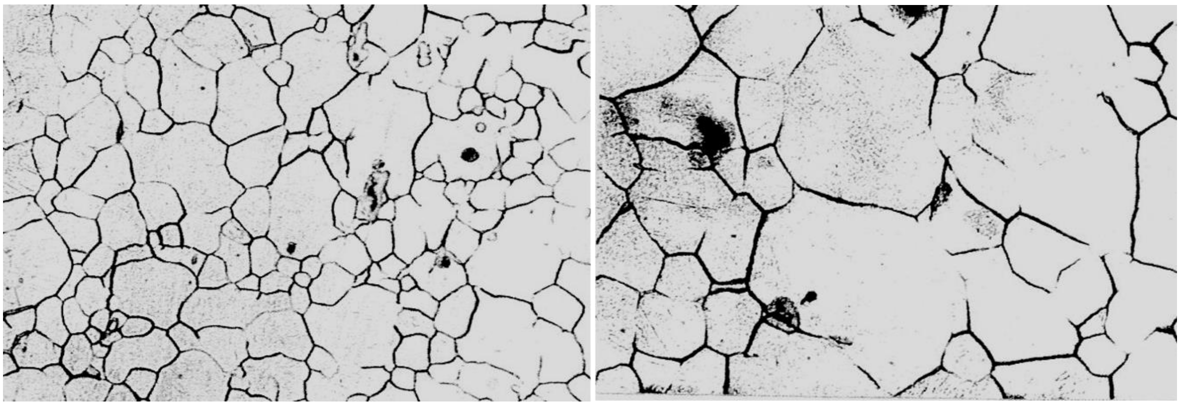
Fig. 1. Austenite structure of the steel with 0.55% C after a 10% reduction in temperatures: (a) -950 and (b) -1,100°C (magnification: x100)

The increase in the carbon content of the steel to 0.65% C did not lead to a qualitative change in the form of grains. Compared to the steel with 0.55% C, for the same temperatures and degrees of reduction (Fig. 1), the austenite structure being formed had an increased average grain size (Fig. 2). Indeed, if one makes the comparison with a 10% reduction in the temperature of 950°C, only the increase in the carbon concentration to 0.65% C led to an increase in value d (Fig. 2a) by 30 μ, which is approximately 30%. At the same time, the inequigranular structure of austenite was in turn increased (Fig. 2a).

The nature of the change in the austenite grain size during hot-reduction of the investigated steels is presented in Figure 3. At the same deformation temperature, the increase in the reduction degree is accompanied by a somewhat expected dispersion of the austenitic structure. On the other hand, in order to explain the influence of carbon content in the steel on value d one can use the following equation [5]:

$$T_r \approx 0{,}4 T_s, \quad (1)$$

where T_r and T_s are the temperatures of recrystallization, at the beginning, and metal smelting, respectively. Taking the *solidus* temperature as T_s from the structural diagram $Fe-C$, after substitution into (1), we find that the growth of 0.1% C reduces *T* by about 30-40°C. Moreover, possible carbon liquation phenomena in the metal microvolumes can further reduce the value of *T*. Thus, the observed austenite structure (Fig. 1 and Fig. 2), after hot-reduction in the studied temperature range, and the nature of the grain size change with its unchanged form indicate almost full completion of the primary recrystallization.



(a) (b)

Fig. 2. Austenite structure of the steel with 0.65% C after a 10% reduction in temperatures: (a) -950 and (b) -1,100°C (magnification: x100)

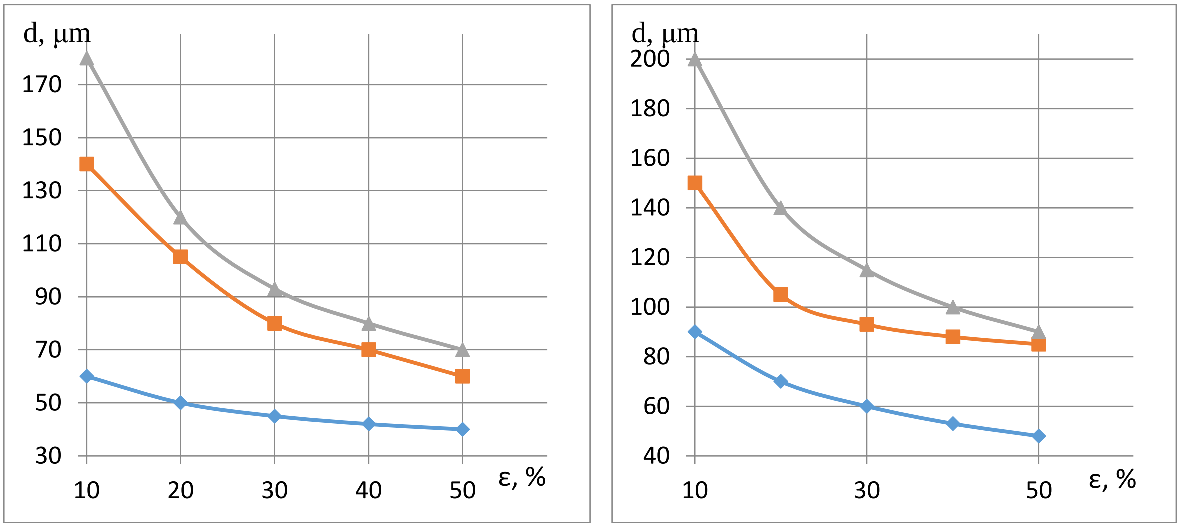
Analysis of the known experimental data [9, 10] shows sufficiently high sensitivity of the initial stages of development of the grain structure's coarsening processes towards the parameters of high-temperature deformation. Compared to the minimum reduction temperature of the present research (950°C), reducing the temperature to 850-750°C [4] leads to refinement of the austenite structure, but only as a result of the use of large deformation degrees and certain degree of holding after its completion. Otherwise, the state of hot-hardening should be maintained. Given that, for the medium-carbon steel at a reduction temperatures above 1,000°C, a 1 sec hold after its completion is sufficient for the formation of fine austenite grains of a polyhedral shape [4, 9], let us estimate the rate by which d decreases for the dependencies in Figure 3. In general terms, the austenite grain size's dependence on the deformation value for a certain temperature can be expressed using the grain square (F):

$$F = A\varepsilon^{-n} \tag{2}$$

where $F = k\sqrt{d}$, k is the form factor, which for the hexagon is 1.86 [6], and A and -n are the constants, which are determined by application the logarithm of (2):

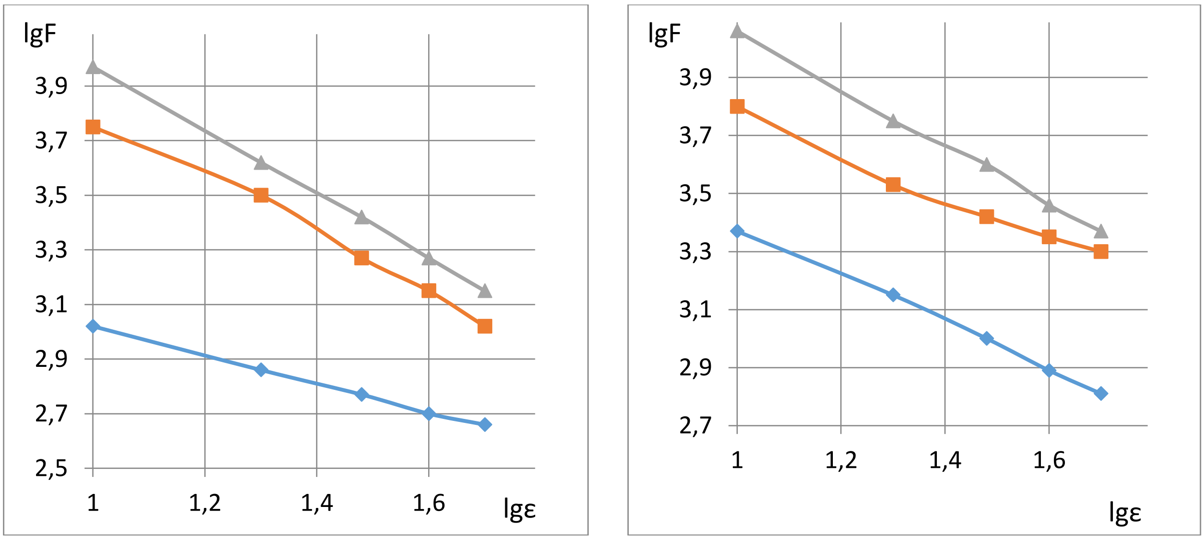
$$\lg F = \lg A - n \lg \varepsilon \tag{3}$$

Using the analysis of the plotted dependencies $\lg F - \lg \varepsilon$ (Fig. 4), $\lg F = \lg A$ at $\varepsilon = 1\%$ and $n = \dfrac{\Delta \lg F}{\Delta \lg \varepsilon}$ were determined as an indicator of the metal sensitivity to the reduction temperature (Table 1).



a b

Fig. 3. The dependence of the austenite grain size of the steel with 0.55% C (a) and 0.65% C (b) on the degree (ε) and temperature (♦: -950°C; ■: -1,100°C; ▲: -1,150°C) of the hot-deformation of the plastic



a b

Fig. 4. Dependence F of the austenite grain of the steel with 0.55% C (a) and 0.65% C (b) on the degree (ε) and temperature (♦: -950°C; ■:-1,100°C; ▲: -1,150°C) of hot-reduction

Formally, from (3), value A should correspond to the austenite grain square (size: d_A) after dependency extrapolation to the 1% reduction for a corresponding temperature, although, according to [1,2], the deformation to 10% at 950°C does not lead to significant changes in the grain size. At the same time, the obtained values of d_A (Table 1) are in reasonably good agreement with the results of similar studies. Thus, according to [4], the medium-carbon steel, after the 10% reduction at the temperature of 950°C, holds up to 5 sec after deformation, such that d_A is 170-200 μm; after the 4-8% deformation, this characteristic reaches 700-800 μm.

Table 1.

Values of austenite grain size

Parameter	0,55% C			0,65% C		
	Temperature, $^\circ C$					
	950	1100	1150	950	1100	1150
$\lg A$	3,57	4,8	5,24	4,2	4,53	5,0
n	0,51	1,04	1,17	0,78	0,8	0,99
$m = 2 - n$	1,49	0,96	0,83	1,22	1,2	1,01
$d_A, \mu m$	115	470	770	240	340	590

The exponent of (2) is in fact a rather complex characteristic defining the conditions of the metal matrix grain growth in the hot-reduction process. Taking into account the existence of a maximum value (n=2) [4,9], the general form of the dependence for n is as follows:

$$n \approx 2 - m - g - s \qquad (4)$$

where m, g and s are the components determining the influence degree on the growth of hot-hardening grain, the presence effect of the sub- and recrystallized structures, and grain growth after hot-deformation. For the conditions of the reduction of the investigated steels, the influence of g and s is absent, such that (4) takes the following form:

$$m \approx 2 - n \qquad (5)$$

Analysis of the values m and d_A (Table 1), depending on the reduction temperature and the carbon content in the steel, indicates the possibility of the existence of relationships between them, which is confirmed by paired plotting of the corresponding values (Fig. 5). As an initial approximation, the increase of m indicates an enhanced role for hot-hardening in the formation of austenitic structure under hot-reduction degrees up to 10%. During deformations less than the critical value, the number of defects in the crystal structure is not enough to form the recrystallization nucleus. On this basis, the duration of the incubation period of the recrystallization centre nucleation will exceed the similar characteristics found at the beginning of substructure transformations. Actually, under these conditions of hot-reduction, rather than grains with large-angle boundaries and increased mobility, the grains are more complex, with reduced energy in connection with the ordered distribution of dislocations in them [4, 11]. Therefore, the formation of a grain structure with boundaries similar to substructural ones should be considered as one of the factors contributing to grain refinement during hot-reduction.

Thus, to improve the uniformity of the austenite grain structure over the rim section of a railway wheel, it is necessary to increase the role of hot-hardening during high-temperature deformation. It is possible to achieve this by using a gradual temperature reduction in the hot-deformation of the plastic when rolling. Indeed, after a certain degree of deformation when forming a rim, even a slight cooling-down (100-150°C) of the surface volumes is sufficient to increase their strength characteristics. Based on this, an increase in the magnitude of the hot-hardening of the austenitic structure in the central rim volumes will occur, which in turn will lead to the formation of a more uniform fine-grain austenite structure over the rim section of the railway wheel.

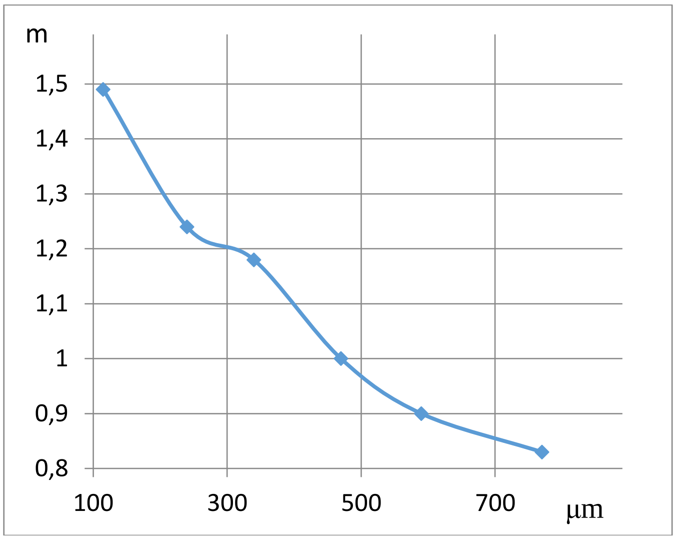


Fig. 5. Mutual change of m and d_A

5. CONCLUSION

1. The formation of a grain structure with boundaries similar to substructural ones should be seen as one of the factors contributing to grain refinement during the hot-reduction of carbon steel.
2. The increase in the magnitude of the hot-hardening of the austenitic structure in the central rim volumes will, in turn, lead to the formation of a more uniform fine-grain austenite structure over the rim section of the railway wheel.

References

1. Бабаченко А.И. 2015. *Надежность и долговечность железнодорожных колес и бандажей.* [In Russian: Babachenko A.I. *Reliability and Longevity of Railway Wheels and Bracers*]. Dnipropetrovsk: PGASA.
2. Данченко, Н.И., О.Н. Перков, Т.А. Гладкова. 1984. *Зависимость усталостной прочности и ударной вязкости колесной стали от ее структурного состояния. Теория и практика термической обработки проката*. [In Russian: N.I. Danchenko, O.N. Perkov, T.A. Gladkova. 1984. *Dependence of Tireless Durability and Shock Viscidity of the Wheeled Steel on Its Structural State*: *Theory and Practice of Rolling Heat Treatment*]. Moscow: Металлургия.
3. Gleiter H., B. Chalmers. 1972. *High-angle Grain Boundaries*. Oxford: Pergamon Press.
4. Бернштейн М.Л. 1977. *Структура деформированных металлов*. [In Russian: Bernshtain M.L. 1977. *Structure of Deformed metals*]. Moscow: Металлургия.
5. Дзугутов М.Я. 1977. *Пластическая деформация высоколегированных сталей и сплавов*. [In Russian: Dzugutov M. 1977. *Plastic Deformation of High Alloy Steels and Alloys*]. Moscow: Металлургия.
6. Вакуленко І.О. 2010. *Структурний аналіз в матеріалознавстві.* [In Ukranian: Vakulenko I.O. 2010. *Structural Analysis in Materiology*]. Dnipropetrovsk: Makoveckiy.
7. Mecking H., F. Kirch. 1971. *Recrystallization of Metallic Materials*. Stuttgart: Verlag.

8. Вакуленко И.А., В.И. Большаков. 2008. *Морфология структуры и деформационное упрочнение стали*. [In Russian: Vakulenko I.A., V.I. Bolshakov. 2008. *Morphology of the Structure and Deformation of Work-hardening Steel*]. Dnipropetrovsk: Makoveckiy.
9. Werner R. 1969. „Kornverfeinerung bei der warmumformung“. [In German: “Grain refinement during hot-forming“]. *Stahl und Eisen* 7: 364.
10. Diaic R.A.P., J.J. Jonas. 1973. „Recrystallization of high carbon steel between intervals of high temperature deformation”. *Metallurgical Transactions* 4(2): 621-624.
11. Хесснер Ф., С. Гофманн. 1982. *Миграция больше угловых границ зерен*. *Рекристаллизация металлических материалов*. [In Russian: Haessner F., S. Gofmann. 1978. *Migration of High-angle Borders of Grains*: *Recrystallization of Metallic Materials*]. Moscow: Металлургия.

Received 09.05.2016; accepted in revised form 25.09.2016