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Prediction of grain size evolution for low alloyed steels

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ABSTRACT

The microstructure of the low alloyed steels after hot plastic deformation and high temperature annealing was described for different regimes of treatment. It was shown, that using of the Avrami- Kolmogorov type equation allows to predict the grain size with accuracy about 7%.

Description and prediction of the microstructure parameters are of great importance for the materials, including the steels and alloys [1,2]. It is especially important for the prediction of mechanical properties of materials. Taking into account that thermal, mechanical, and thermo-mechanical treatments are widely use as stages of manufacturing process for steels it is necessary to find a way to describe the recrystallization process at different temperatures. One of the possible ways is to describe it with the use of volume fraction and mean size of recrystallized grain [3–5]. In present paper, these data were described using the Avrami- Kolmogorov type equation for two types of steels.

The chemical compositions in weight percent are: steel 1 (0.17 C, 2.05 Cr, 0.6 Mo, 0.11 V, 1.4 Ni) and steel 2 (0.29 C, 1.6 Cr, 0.4 Mo, 0.1 V, 3.1 Ni) The following set of equations was used for calculation of the volume fraction (X_{DRX}) of recrystallized grains after hot plastic deformation:

$$\varepsilon_p = a_1 \cdot d_0^{n_1} \cdot \dot{\varepsilon}^{m_1} exp\left[\frac{Q_1}{RT}\right] \quad (1)$$

$$\varepsilon_{0.5} = a_5 \cdot d_0^{n_5} \cdot \dot{\varepsilon}^{m_5} \cdot exp\left[\frac{Q_5}{RT}\right] \quad (2)$$

$$X_{DRX} = 1 - exp\left[-\beta_d \cdot \left(\frac{(\varepsilon - \varepsilon_p)}{\varepsilon_{0.5}}\right)^{k_d}\right] \quad (3)$$

$$\varepsilon_c = a_2 \varepsilon_p \quad (4)$$

In these equations d_0 is initial grain size, $\varepsilon_{0,5}$ is deformation, corresponding to 50% of recrystallized grains; ε is current deformation value, ε_p *and* ε_c are peak strain on the stress–strain curve and critical strain when the dynamic recrystallization begins respectively. Other values are parameters, which must be determined in experiment.

In order to determine these parameters the samples were plastically deformed and the grain size at different stages of the hot plastic deformation at the temperatures 900, 1080 and 1230 °C was measured. The Gleeble 3800 unit was used for experiments. Deformation rate varied from 0.1 to 50 s^{-1}. Typical deformation curves are shown on Fig. 1. By the rectangles the zones of curves taken for mathematical treatment are shown. After, the obtained parameters (Table 1) were used for automatic recalculation at other deformation regimes (different deformation rate and temperatures equal to 980 and 1050 °C). The dimensions of used values are as follow: Q_i – J/mol; d_0 – μm; deformation rate ($\dot{\epsilon}$ – 1/s; deformation (ε_i), a_2, n_i, m_i are dimensionless parameters; and a_1 and a_5 are formally corresponds to these units.

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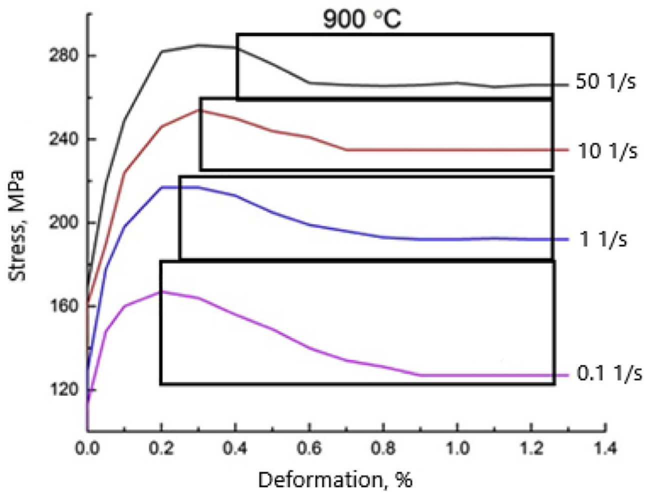

Fig. 1. Typical stress–strain curves obtained for different deformation rate (indicated at picture) at 900 °C. Rectangles demonstrate the region, taken for parameters determination.

Grain size d_{DRX} evolution was described by the following equation:

$$d_{DRX} = c_8 + a_8 \cdot d_0^{h_8} \cdot \dot{\varepsilon}^{m_8} exp\left[\frac{Q_8}{RT}\right] \quad (5)$$

Results of calculation were compared with experiments at corresponding temperatures and are presented on Figs. 2 and 3.

Besides, by the same method the mean grain size of non-deformed materials was calculated with the use of the following equation:

$$d_{gg} = \left[d_0^m + a_9 t \exp\left(-\frac{Q_9}{RT}\right)\right]^{\frac{1}{m}}, \quad (6)$$

where d_0 is initial grain size, other numbers are parameters to be determined.

As one can see, this approach allows to describe satisfactory the mean grain size for chosen steels. It can be also used for different single phase materials.

Table 1
The values of kinetic parameters of the set of Eqs. (1)–(4).

Material	m_1	Q_1	n_1	a_1	m_5	Q_5	n_5	a_5	β_d	k_d	a_2
Steel 1	0,128	26,932	0,029	0,027	0,099	32,637	0,076	0,022	10,05	3,42	0,83
Steel 2	0,048	10,895	0,019	0,092	0,044	7892	0	0,223	17,8	3,74	0,83

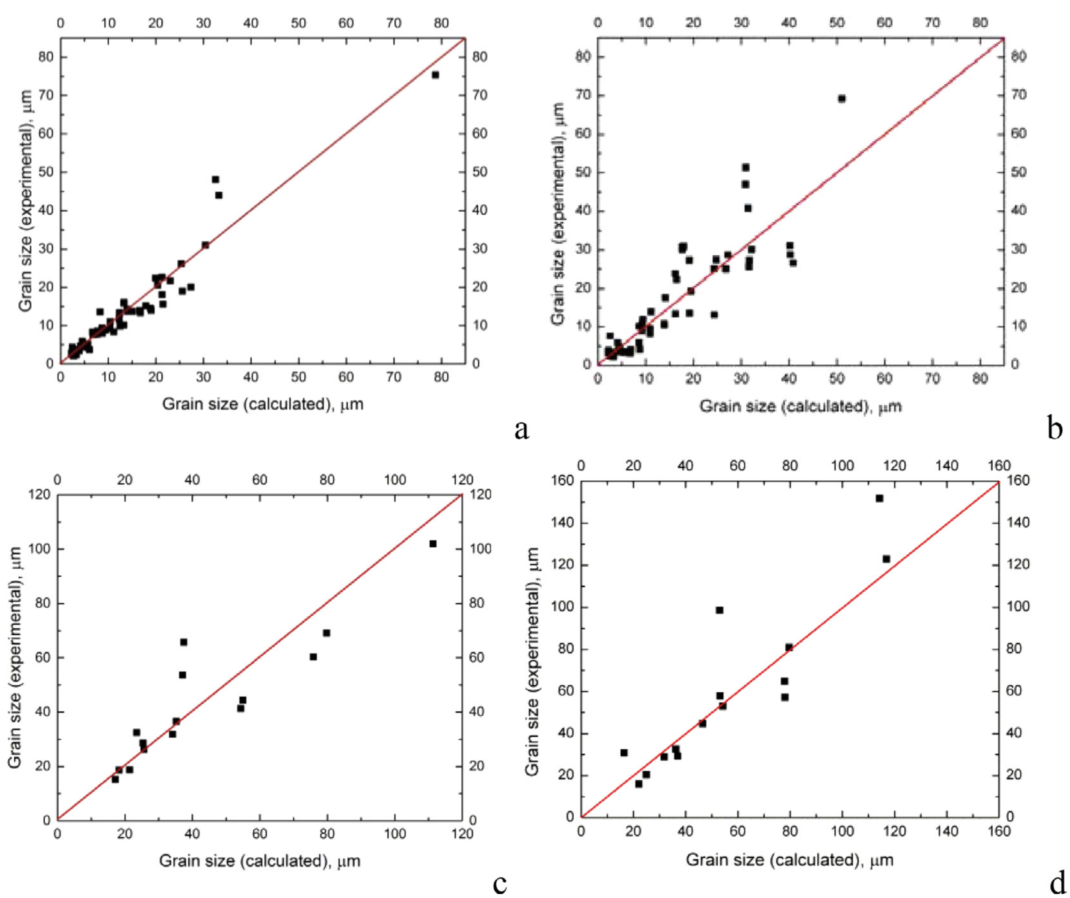

Fig. 2. Correlation between measured and calculated values of grain sizes (for all set of thermo-mechanical treatments) for steel 1 (left) and 2 (right) after hot plastic deformation (a and b) and annealing (c and d).

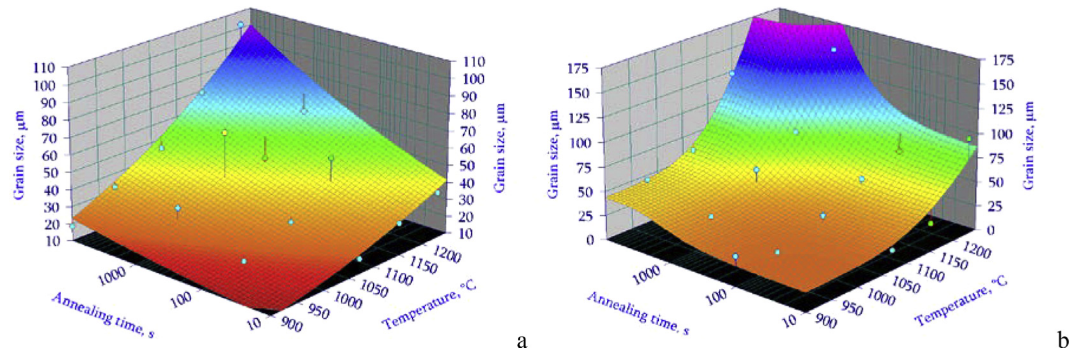

Fig. 3. Experimental results of grain sizes for steel 1 (a) and steel 2 (b) as a function of time–temperature regime of annealing.

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