

1 Description of the microstructure model

For the microstructure simulation, a semi-empirical model will be used on the basis of the formulations of Sellar [1]. The practical transformability of the model has already been confirmed in numerous publications [2-7].

1.1 Dynamic recrystallization

When exceeding the critical grade of metal forming, the microstructure of metallic materials recrystallizes during the metal forming dynamically:

$$\varphi_c = a_1 * D_0^{a_2} * Z^{a_3} \quad (1)$$

in which: D_0 – initial grain size

Z – parameter Zener-Holloman

$a_1...a_3$ – material-dependent coefficients

The strain $\varphi_{0,5}$, in which 50% of the microstructure are recrystallized, is to be determined as follows:

$$\varphi_{0,5} = c_1 * D_0^{c_2} * \dot{\varphi}^{c_4} * e^{\left(\frac{c_3}{T}\right)} \quad (2)$$

in which: $\dot{\varphi}$ – strain-rate

T – temperature

$c_1...c_4$ – material-dependent coefficients

The dynamically recrystallized content X_{dyn} represents the percentage of the recrystallized microstructure:

$$X_{dyn} = 1 - e^{e_1 * \left[\frac{\varphi - \varphi_c}{\varphi_{0,5}}\right]^{e_2}} \quad (3)$$

in which $e_1...e_2$ – material-dependent coefficients

A very high grain refining can be obtained with the dynamic recrystallization. The preset grain size D_{dyn} depends, above all, on the activation energy of the respective material, on the metal-forming speed and on the metal forming temperature. For the determination there will be used the following relation:

$$D_{dyn} = d_1 Z^{d_2} \quad (4)$$

in which: $d_1...d_2$ – material-dependent coefficients

In this connection, the coefficients $a_1...a_3$, $c_1...c_4$, d_1, d_2 , e_1 and e_2 are material-dependent factors which are to be determined by experiments.

1.2 Static recrystallization

The static recrystallization will be marked by the description of the time for the 50% static recrystallization, by the statically recrystallized content and by the statically recrystallized grain size.

$$X_{stat} = 1 - e^{-h_1 * \left[\frac{t_p - t_o}{t_{0,5}} \right]^{h_2}} \quad (5)$$

$$t_{0,5} = f_1 \varphi^{f_2} D_0^{f_3} \left[\varphi * e^{\frac{Q_{st}}{RT}} \right]^{f_4} * e^{\frac{f_5}{T}} \quad (6)$$

in which: t_p dead time
 t_o time until the beginning of the static recrystallization
 D_0 initial grain size before starting the static recrystallization
 Q_{st} activation energy for the static recrystallization
 $h_1, h_2, f_1 \dots f_5, g_1 \dots g_4$ – material-dependent coefficients

$$D_{stat} = g_1 \varphi^{g_2} D_0^{g_3} Z^{g_4} \quad (7)$$

$h_1, h_2, f_1 \dots f_5$ as well as g_1 up to g_4 are the material-dependent constants for the modelling. D_0 is the initial grain size before starting the static recrystallization.

1.3 Grain growth

After a primary recrystallization, the microstructure is not yet in the state of equilibrium. A reduction of the grain boundary energy by a decrease of the grain boundary area can be realized through the grain growth:

$$(\Delta D)^n = \lambda * t * e^{\frac{-Q_{KW}}{RT}} \quad (8)$$

in which: t holding time
 ΔD grain size difference
 Q_{KW} activation energy for the grain growth
 λ, n – material-dependent coefficients

λ and n are material-dependent coefficients for the modeling.

References

- [1] Sellars, C.M.; Whiteman, L.A.: in Proc. Product Technology Conf. on "Controlled rolling processing of HSLA-steels". York 1976
- [2] Spittel, T.; Spittel, M.: Forschungsbericht an GMT (Research Report to GMT), 2003
- [3] Borowikow, A.: Modellbetrachtungen zur Ver- und Entfestigung höherfester schweißbarer Feinkornstähle (Model reflections concerning the work hardening and the removal of work hardening of higher-tensile weldable fine grain steels). TU Bergakademie Freiberg, Berg- und Hüttenmännischer Tag 1990

- [4] Lehnert, W.; Nguyen D. C.; Wehage, H.: "Simulation of austenitic microstructure in rod and wire rolling of quenched and tempered steel grades." Steel research 66 (1995) No.11
- [5] Lehnert, W.; Nguyen, D. C.; Wehage, H.: „Werkstoffgefüge beim Walzen von Draht und Stabstahl.“ ("Material structure in rod and wire rolling") Wire 44(1993) 10
- [6] Lehnert, W.; Nguyen, D. C.; Wehage, H.; Werners, R.: „Simulation der Austenitkornfeinung beim Walzen“ ("Simulation of the austenite grain refining at the rolling"). Steel and Iron 113 (1993) No. 6
- [7] Wehage, H.; Skoda- Dopp, U.; Quitmann, U.; Sauer, W.: „Stichplansimulation und – optimierung für das Warmflachwalzen“ (Pass schedule simulation and optimization for the hot flat rolling"). MEFORM 98 . Umformtechnisches Seminar Modellierung von Umformprozessen am Institut für Metallformung der TU Bergakademie Freiberg, (Seminar for the Metal-Forming Engineering Modelling of metal-forming processes at the institute for Metal Forming of the TU Bergakademie Freiberg) February 1998