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The model of prediction of the microstructure austenite C-Mn steel

B. Koczurkiewicz*
Institute of Modelling and Automation Plastic Working Processes,
Czestochowa Univesity of Technology,
Al. Armii Krajowej 19, 42-200 Czestochowa, Poland
* Corresponding author: E-mail address: koczur@mim.pcz.czest.pl

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ABSTRACT

Purpose: The subject of the work is analysis of author's model for prediction of austenite microstructure of C-Mn steel based on Sellar's solution.

Design/methodology/approach: The present study adopts the Sellar's solution for C-Mn steel to the prediction of phenomena occurring in the steel and the grain size of austenite

Findings: The developed model for the evolution of the austenite microstructure enables the correct determination of the grain size of austenite formed by multi-stage hot deformation.

Research limitations/implications: The model is limitated only for selected steel group

Practical implications: The results obtained on the basis of this model will be utilized in the study for the determination of the distribution and state of microstructure in sections with complicated shapes after the rolling process.

Originality/value: The modelling of microstructure is very importante problem. There are a lot of general models in literature, which can be used for predicting evolution of microstructure after rolling proces of steel, but the results obtained from them are different. There is a need for adapting the general model for a selected steel group to the prediction of phenomena occurring in the steel and the grain size of austenite formed by means of multi-stage deformation.

Keywords: Numerical techniques; Microstructure; Modelling of microstructure; Austenite

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

A considerable number of works devoted to modelling of the microstructure and mechanical properties of steel formed by plastic working have been published to date; nevertheless, the problem of predicting them for products after hot rolling and cooling has not been satisfactorily solved yet. Numerous models are proposed in literature [1÷5], which can be used for predicting the development of microstructure for particular groups of steel. However, the application of a general model for a specific steel grade causes the simulation results to deviate from the actual results. Hence, there is a need for adapting the general model for a selected steel grade. This will enable a more accurate prediction of microstructural changes in the steel used during model studies [6,7]. The present study adopts the Sellars solution for C-Mn steel to the prediction of phenomena occurring in the steel and the grain size of austenite formed by means of multi-stage deformation[8].

2. Theoretical researches

Presenting plastic working processes in a manner that allows the determination of phenomena occurring in the material enables

the accurate prediction of the grain size of austenite prior to the ferritic transition and the value of transferred deformation. This is of particular importance when designing a technology for the manufacture of sections that are characterized by preset mechanical properties. For predicting the parameters of microstructure of austenite after rolling processes, a computer program relying on the Sellars model was built according to the algorithm shown in Fig. 1.

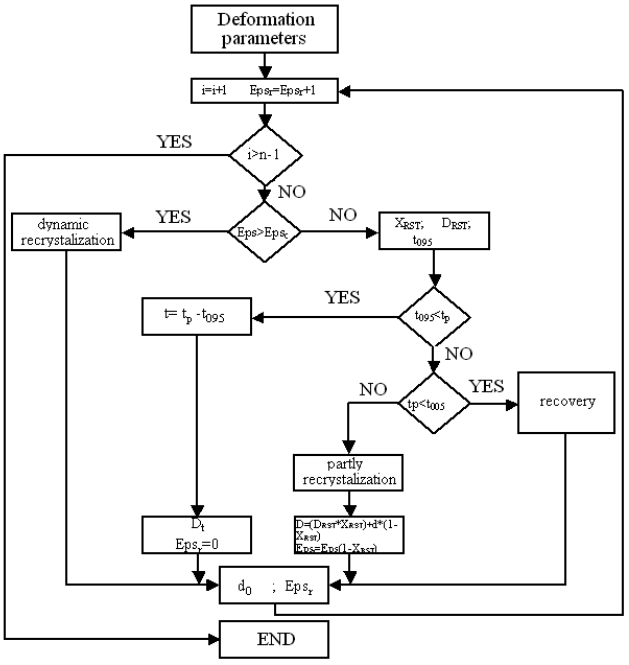

Fig. 1.Block diagram of programme for prediction of austenite grain size

Based on the rolling process parameters (the number of passes, the times of breaks between the passes, the magnitudes of deformations and deformation speeds in passes), it is possible to establish the phenomena occurring in the steel after deformation and to determine the austenite grain size and the non-recrystallized strain. For the description of the kinetics of the phenomena occurring in the material being deformed, equation [9] was used.

The computer program is composed of functional modules describing the phenomena that occur during recrystallization and recovery. The type of occurring recrystallization is dependent on the deformation. If its value exceeds the critical value, then phenomena associated with dynamic and meta-dynamic recrystallization will take place in the material.

$$\varepsilon_c = A\varepsilon_p \tag{1}$$

$$\varepsilon_p = Bd\gamma_0^{\,n_{dyn}} Z^{p_{dyn}} \tag{2}$$

$$Z = \dot{\varepsilon}\exp[\frac{Q}{RT}] \tag{3}$$

ε_c- critical deformation for dynamic recrystallization, ε_p- deformation comply with the maximal stress, $d\gamma_o$- started grain size of austenite, $\dot{\varepsilon}$- deformation rate[1/s], $A=1$, $B=4{,}88\ 10^{-4}$, $n_{dyn}=0{,}9$, $p_{dyn}=0{,}17$, Z – Zener-Hollomon parameter, Q – activation energy:

$$Q = 282{,}7 - 92[C] - 6{,}57[Mn] - [Si] \tag{4}$$

Otherwise, phenomena associated with static recrystallization are considered in the material. The times characterizing the kinetics of phenomena have been determined from the equations:

- half time recrystallization [10]:

$$t_{05} = bd\gamma_0^{\,q}\varepsilon^{p_1}\exp(\frac{300000}{RT}) \tag{5}$$

$d\gamma_o$ - austenite grain size [μm], ε- strain, T – temperature [K], $b=2{,}5\ 10^{-19}$, $q=2$, $p_1=-4$.

- full time recrystallization [11]:

$$t_{095} = (4{,}323)^{\frac{1}{n_1}} t_{05} \tag{6}$$

t_{05} – half time recrystallization [s], $n_1=1{,}6$.

- start time recrystallization:

$$t_{005} = t_{05}\frac{\ln(0{,}95)}{-0{,}693} \tag{7}$$

t_{05} – half time recrystallization.

In the case of partly recrystallization (X<1) the austenite grain size was computed by equation:

$$D = (D_{rex}X) + d\gamma_0(1-X) \tag{8}$$

$d\gamma_0$ - austenite grain size [μm], D_{rex} - austenite grain size after static recrystallization [μm], X – volume of recrystallization

and strain not recrystallized ε_r [12]:

$$\varepsilon_r = \varepsilon(1-X) \tag{9}$$

ε- strain; X – volume of recrystallization.

In the case, where the time between the successive passes is less than the time needed for occurring 5% of recrystallization, the recovery of the material follows, during which the average austenite grain size does not change, but the magnitude of strain accumulated in the material decreases. Its variation is defined by the coefficient k_{zdr} [12]:

$$\varepsilon_{r\,zdr} = k^{-1}\varepsilon_r \tag{10}$$

$$k_{zdr} = 1 + \varepsilon t_{zrd}\,0{,}23\exp(-\frac{330000}{RT})10^{(10{,}8+\frac{33400}{RT})} \tag{11}$$

ε_γ– strain not recrystallized, t_{zdr} – recovery time [s], T – temperature K.

3. Model verification

In order to verify the model applied, the comparative analysis of results obtained from the developed model was compared with the results obtained from models most frequently quoted in literature, namely those of Choquet [13], Roberts [14] and Yada [15]. Results obtained for the initial austenite grain size range $d\gamma$=50÷150 μm, temperature range 850^0C÷1125^0C and deformation range from 0.1 to 0.8. The exemplary computation results are shown on Fig. 2÷6. On fig. 2 are shown relationship between recrystallization volume and time for deformation

ε =0,25; temperature T= 900^{0}C and initial austeniete grain size dγ=100μm. From the diagrams it can be found that the results obtained from the author's model of microstructure evolution do not deviate from the results obtained based on Choquet's, Roberts' and Yada's models for the analyzed range of parameters.

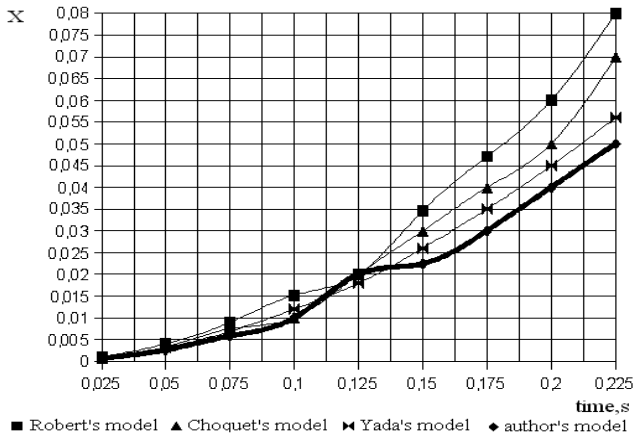

Fig. 2. Changes of recrystallization volume X in time after deformation step (ε =0,25; T= 900^{0}C; dγ=100μm)

On figure 3 are shown the variations of times needed for occurring 50% of recrystallization, depending on the band temperature for deformation ε =0,5 and initial austenite grain size dγ=100μm.

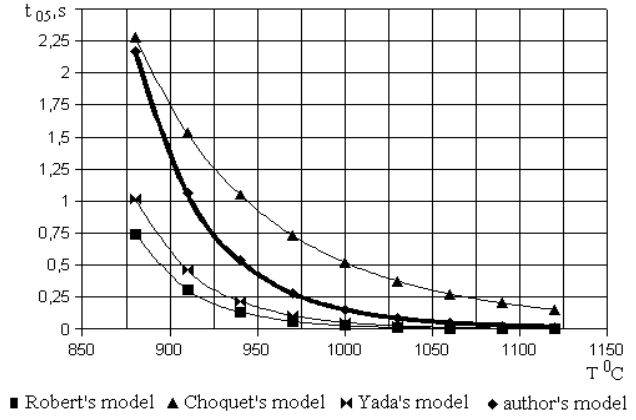

Fig. 3. Changes of half time recrystallization t_{05} in temperature (ε=0,5; dγ=100μm)

the austenite grain sizes and strains examined, the author's model produced average values compared to the values yielded by comparable models.

The changes of half time recrystallization t_{05} in function of deformation volume are shown on fig. 4. Results obtained for the initial austenite grain size of dγ=100 μm and for temperature 850^{0}C. The values of falf time recrystallization obtained from author's model produced average values compared to the values yielded by comparable models by the deformation range from 0.7 to 0.15.For the deformation lower then 0.15 the results obtained from the author's model are lower but they still in the range of values obtained from Choquet's, Roberts' and Yada's models.

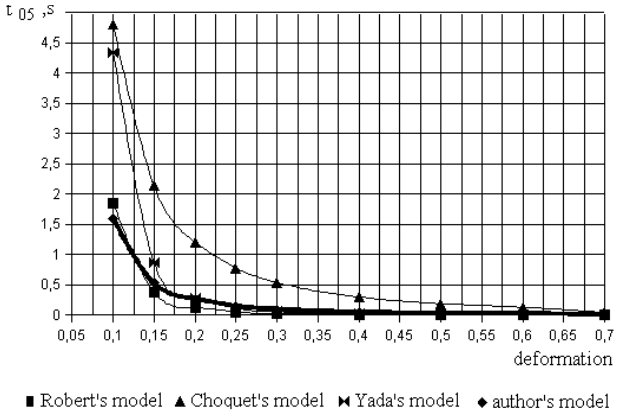

Fig. 4. Changes of half time recrystallization t_{05} in deformation (T= 850^{0}C; dγ=100μm)

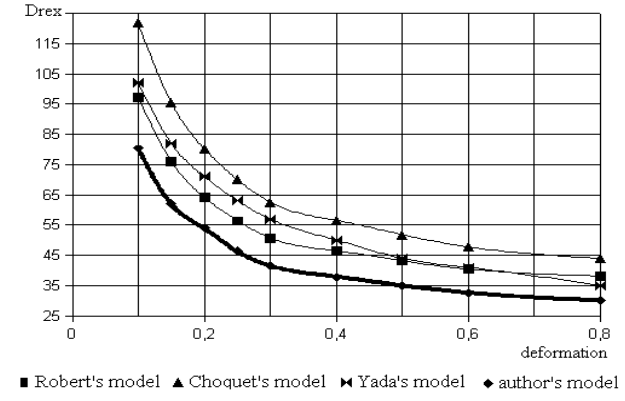

Fig. 5. Changes of recrystallized austenite grain size D_{rex} in function of deformation (T=1100°C; dγ=100μm)

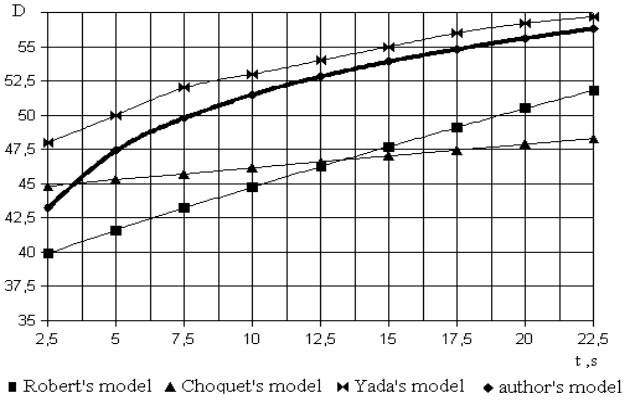

Fig. 6. Austenite grain size after the grow process (ε =0,5; T=1100°C, dγ=100μm)

The variations in the grain size of austenite after static recrystallization, D_{rex}, as a function of deformation are shown on fig. 5. The graphs have been plotted for an initial austenite grain size of $d\gamma$=100μm and a temperature 1100°C. From the data shown in these figures it can be observed that the results obtained from the author's model are comparable to the results obtained from the models most frequently quoted in literature.

The variations in the austenite grain size, $D\gamma$, after the growth process as a function of time are presented on fig. 6. Results obtained for the strain ε=0,5 initial austenite grain size of $d\gamma$=100 μm for temperature 1100^0C.

The data shown in fig. 6 indicate that, within the strain ε=0,5 and at the temperatures analyzed, the results obtained using the author's model are close to the results obtained from other models.

4. Conclusions

On the basis of the performed comparative analysis of the results obtained from the author's model with the results obtained based on Choquet's, Roberts' i Yada's models it can be stated that the developed model for the evolution of the austenite microstructure enables the correct determination of the grain size of austenite formed by multi-stage hot deformation. It can be used for modelling the processes of hot plastic working of products of C-Mn steel. The results obtained on the basis of this model will be utilized in the study for the determination of the distribution and state of microstructure in sections with complicated shapes after the rolling process.

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