MODEL OF THE MICROSTRUCTURE EVOLUTION FOR THE STEEL WITH BORON FOR A COLD UPSETTING

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Abstract

The paper present the concept of a mathematical model for predicting changes in the microstructure of the austenite steel for cold upsetting, the research was carried for 30MnB4 23MnB4 steel grade. Microstructure evolution model is based on the classic Sellars model developed by taking into account the parameters of plastic forming processes and their impact on the processes occurring in the deformed steel. The coefficients of mathematical equations describing the evolution of deformed austenite microstructure were calculated based on the results of experimental studies carried out in the Institute of Plastic Working and Safety Engineering Czestochowa University of Technology.

For the verification of the accuracy developed model laboratory studies were conducted using a metallurgical processes simulator Gleeble 3800. Comparison of the results obtained in the theoretical and experimental studies have confirmed good agreement developed model of the microstructure evolution for the steel with boron for a cold upsetting.

Keywords: Microstructure prediction, hot rolling, boron steels

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, 2], 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. The present study adopts the Sellars solution for boron steel to the prediction of phenomena occurring in the steel and the grain size of austenite formed by means of multi-stage deformation. Boron is added as a alloying elements in many conventional metallic materials improving hardenability, as well as special purpose alloys, such as in magnetic materials obtained by various methods [3].

2. PREDICTION OF AUSTENITE GRAIN SIZE IN BORON STEELS

The 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 presented mechanical properties [4]. 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**. 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.

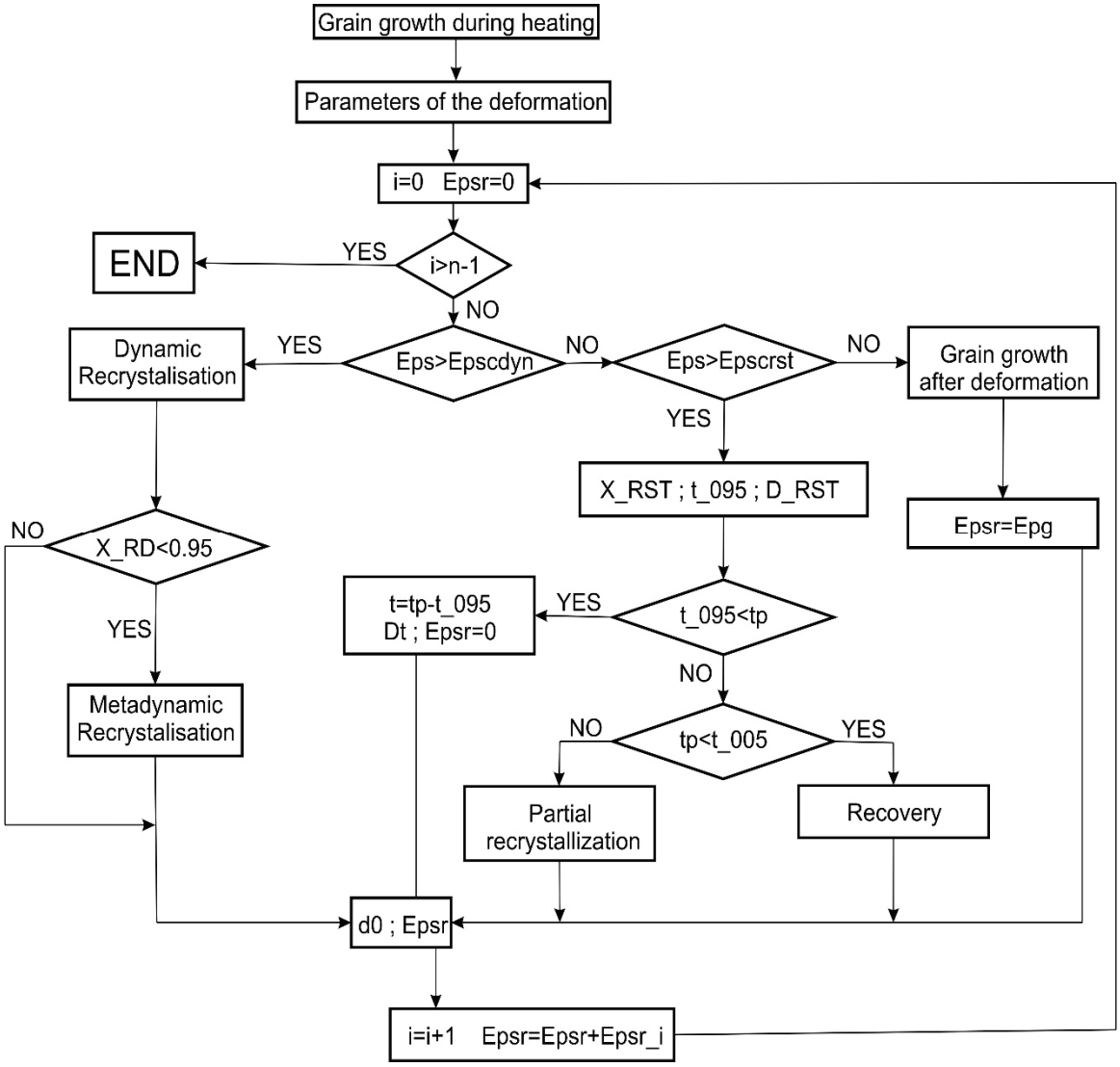

Fig. 1 Block diagram of algorithm for prediction of austenite grain size in boron steels

The algorithm is describing the phenomena that occur during recrystalisation and recovery. The type of occurring recrystallization is dependent on the deformation. If it is exceeds the critical value, then phenomena associated with dynamic and meta-dynamic recrystallisation will take place in the material. The volume of dynamic recrystallization X_RD, volume of meta-dynamic recrystallization X_MRD and average grain size of austenite D_AVG are calculated. Critical deformation for dynamic recrystallization is described by equation 2.

$$\varepsilon_c = A\,\varepsilon_p \tag{2}$$

$$\varepsilon_p = Bd\,\gamma_0^{n_{dyn}} Z^a \tag{3}$$

$$Z = \dot{\varepsilon}\exp\left[\frac{Q}{RT}\right] \tag{4}$$

$$\varepsilon_{cRST} = C\,d\,\gamma_0 Z^q \tag{5}$$

$$D_{growth} = 450\,\varepsilon^d\,\gamma_0^e Z^h \tag{6}$$

where: ε_c - critical deformation for dynamic recrystallization; ε_p - peak deformation; $d\gamma_0$ - initial austenite grain size, μm; Z - Zener - Hollomon parameter; T - temperature, K; Q - energy , J/mol K; A,B,C,d_{dyn}, a, d,e,h,q - coefficients.

Otherwise, phenomena associated with static recrystalllisation are considered in the material. Critical deformation for static recrystallization is described by equation 5. The volume of static recrystallization X_RST and average grain size of austenite D_AVG are calculated. If deformation value is less than the critical value for static recrystallization, then grain grow after deformation will take place in the material (equation 6). After completion of the processes related to the recrystallization may be austenite grain growth. In the case, when volume of recrystallization is less than 1 (partial recrystallization or non-full metadynamic recrystallization) deformation is accumulated in material, and increasing volume of deformation in next step.

In order to determine the coefficients of equations Sellars model physical modelling was carried out using a metallurgical processes Gleeble 3800 simulator. The plasticity curves in the temperature range from 800 to 1200 ºC and in the range of strain rates from 0.1 to 100 s^{-1} were determined. On the basis of the results of the plasticity curves, the peaks of .train of dynamic recrystallization were obtained. Exemplary plasticity curves are presented on **Fig. 2**. For the strain rate of 0.1 s^{-1} for both presented temperatures and for the strain rate of 1 s^{-1} (for the temperature of 900 °C) it can be found, the dominant mechanism is static recrystallization. For other cases the dominant mechanism are dynamic and meta-dynamic recrystallization.

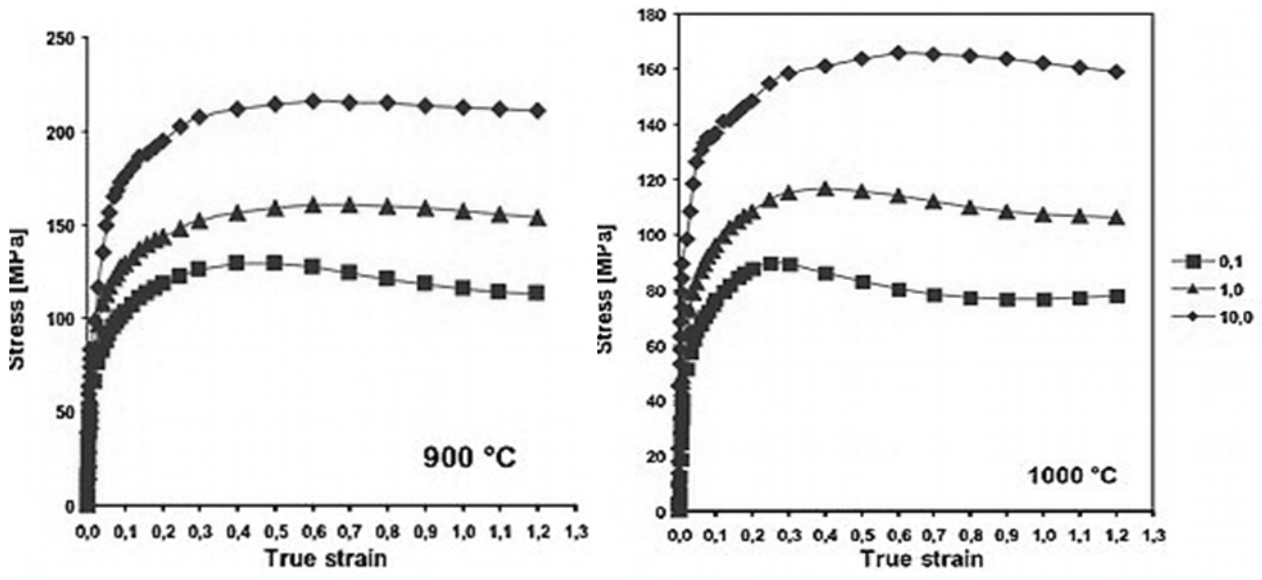

Fig. 2 Exemplary strain - stress dependency for the analysed steel recorded in plastometric test in temperature 900 and 1000 °C

On the basis of the mathematical model computer program for predicting the grain size of austenite formed by a multi-step deformations was built. Developed computer program has a modular structure, in which each module contains a model of quantitative description of the phenomena depending on the preset control parameters. The computer program is equipped with clear user interface. In **Fig. 3** shows the dialog box for entering the initial data (initial austenite grain size, number of passes). As a result of simulation using the developed program it is possible to determine the grain size of austenite formed by multistep deformation and removing strengthening phenomena. The average grain size of austenite is obtained as a function of volume of recrystallization.

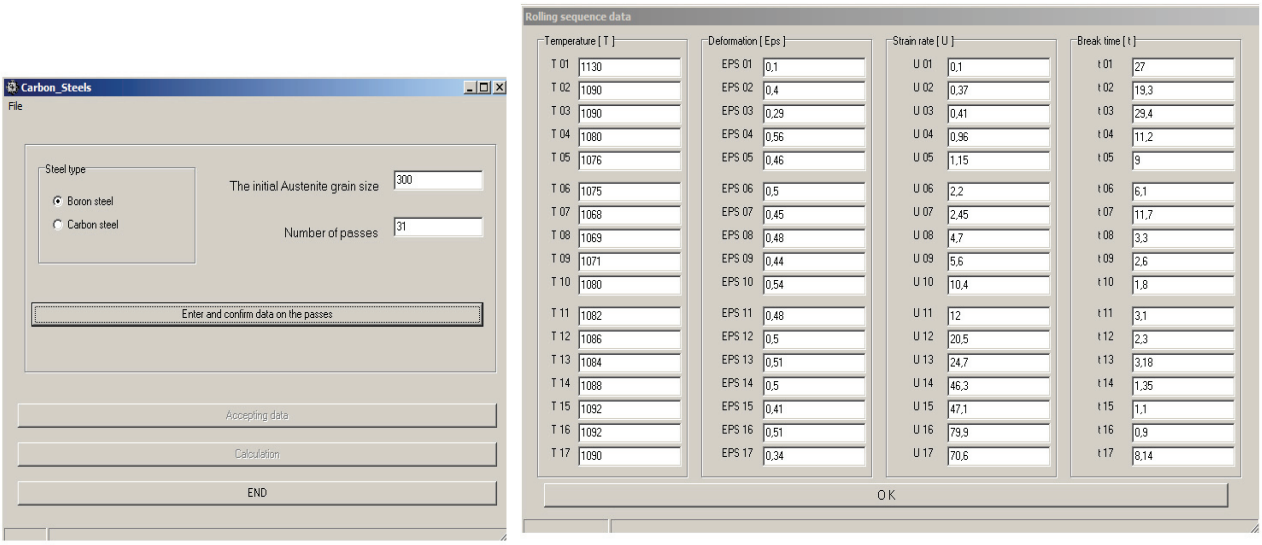

Fig. 3 Interface of Carbon_Steel_2015 program to calculate austenite microstructure in boron steels

3. LABORATORY VERIFICATION OF THEORETICAL MODEL OF THE AUSTENITE GRAIN SIZE PREDICTION IN BORON STEELS

In order to verify the model applied, the results obtained from the developed model were compared with the results obtained from physical simulations. For determined initial austenite grain size thermal treatment using dilatometer DIL 805A/D were done. Samples were heated to temperature 1050 °C, annealing 5 minutes and quenched. Metallographic tests were done and former austenite grain size was determined. Size of former grain size was 62 μm. Using Gleeble 3800 simulator deformations tests with quenching were done. Samples were heated to temperature 1050 °C, annealing 5 minutes and deformed. After deformation samples were quenched and former grain size of austenite were determined. The parameters of deformations for five different deformation - temperature variants are presented in **Table 1**. In the **Table 1** it is also presented average diameter of the austenite former grain size obtained in laboratory tests and in the computer program based on the used model. In **Fig. 4** there are presented microstructures of the samples deformed according to variants III and IV (**Table 1**). When analysing the data presented in **Fig. 4a** it can be seen that for the multistep deformation with all strains equal to 0.2 (variant III) the structure of austenite was more fine-grained as compare with multistep deformation with all strains equal to 0.1 (variant IV). The cause of formation of fine-grained austenite is exceeding of peak deformation (e_{peak}=0.19) and dynamic recrystallization start.

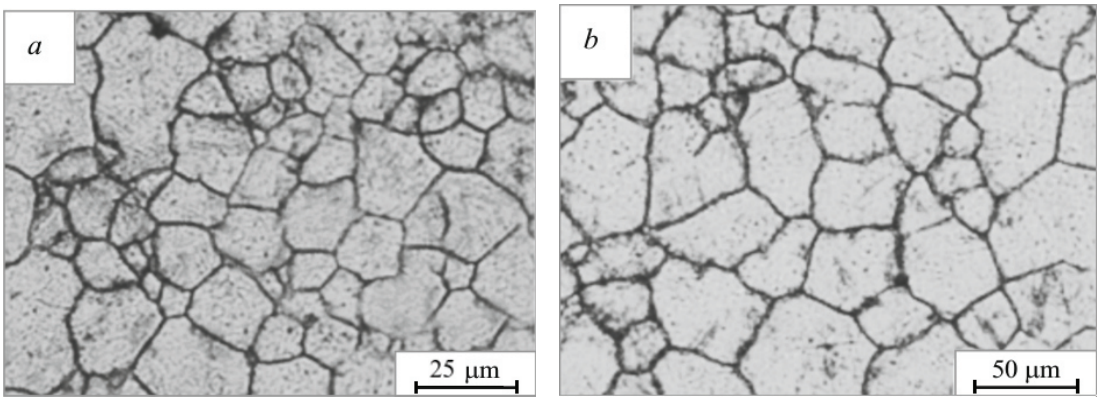

Fig. 4 Microstructure of the test samples deformed according to variant III (a) and variant IV (b)

In studies It was assumed that a safe margin of error obtained between the experimental results and theoretical should not exceed 10 %. As it can be noticed for the testing variants only for the variant III the difference between the austenite former grain size estimated in laboratory test and from theoretical model is more than 10 %, for other cases difference not exceeded 10 %. Future studies will address the topic represented by in reducing the maximum error value below 10 %.

Table 1 The parameters of deformation during verification tests and determined austenite former grain size

No of sample	Parameters of deformations (temperature, strain, strain rate) T [°C], ε, u [1/s]	Austenite former grain size μm		
		Test	**Model**	**Δ%**
I	T_1=1000, ε_1=0.9; T_2=980, C_2=0.3; u=1	12	11.2	**6.7**
II	T_1=1000, ε_1=0.6; T_2=980, ε_2=0.3; T_3=960, ε_3=0.3; u=1	10	10.5	**5.0**
III	T_1=1000, ε_1=0.2; T_2=980, ε_2=0.2; T_3=960, ε_3=0.2; T_4=940, ε_4=0.2; T_5=920, ε_5=0.2, T_6=900, e_6=0.2; u=5	18	21.	**16.7**
IV	T_1=1000, ε_1=0.1; T_2=980, ε_2=0.1; T_3=960, ε_3=0.1 T_4=940, ε_4=0.1; T_5=920, ε_5=0.1; T_6=900, ε_6=0.1; u=10	40	37.1	**7.5**
V	T_1=1000, ε_1=0.25; T_2=980, ε_2=0.22; T_3=960, ε_3=0.2 T_4=940, ε_4=0.18; T_5=920, ε_5=0.16; T_6=900, ε_6=0.15; u=10	28	25.9	**7.2**

Next stage of research was to compare results found form industrial rolling process of 5.5 mm in diameter wire rod of cold upsetting 23MnB4 steel grade with results obtained by developed model. The calculation of microstructure of austenite grain size was made for parameters of deformation presented in work [6]. The average grain size of austenite after industrial rolling process was 28 μm. For the same conditions of deformation average grain size predicted by developed model was 25.5 μm. Estimated results confirmed high accuracy of presented model for prediction of austenite grain size in hot rolled steels with voron addition.

4. CONCLUSION

The concept of a mathematical model for predicting changes of austenite microstructure of steel for cold upsetting is presented in article. For microstructure evolution model of Sellars was adopted. The coefficients of mathematical equations describing the evolution of deformed austenite microstructure were calculated based on the results of experimental studies carried out in the Institute of Plastic Working and Safety Engineering Czestochowa University of Technology.

For the verification of the accuracy developed model laboratory studies were conducted using a metallurgical processes simulator Gleeble 3800. On the basis of the performed verification it can be stated that the developed model for the evolution of the austenite microstructure in steels with boron enables the correct determination of the grain size of austenite formed by multi-stage hot deformation. Comparison of the results obtained in the theoretical and experimental studies have confirmed good agreement developed model of the microstructure evolution for the steel with boron for a cold upsetting.

ACKNOWLEDGEMENTS

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