

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 modeling 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 preset 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 recrystalisation is dependent on the deformation. If its exceeds the critical value, then phenomena associated with dynamic and meta-dynamic recrystalisation will take place in the material. The volume of dynamic recrystalization X_RD, volume of metadynamic recrystalization X_MRD and averge grain size of austenite D_AVG are calculated. Critical deformation for dynamic recrystalization desribe by equation 2.

$$_{c} = A_{p}$$
 (2)

$$_{p}=Bd \quad _{0}^{n_{dyn}}Z^{a} \tag{3}$$

$$Z = \dot{u} \exp[\frac{Q}{RT}]$$
(4)

$$_{cRST} = C d \quad _{0} Z^{q} \tag{5}$$



$$D_{growth} = 450 \quad \overset{d}{} \quad \overset{e}{} \quad 0 Z^h \tag{6}$$

where: $_{c}$ - critical deformation for dynamic recrystalization; $_{p}$. peak deformation; d $_{0}$. initial austenite grain size, m; 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 recrystalisation are considered in the material. Critical deformation for static recrystalisation described by equation 5. The volume of static recrystalisation X_RST and average grain size of austenite D_AVG are calculated. If deformation value is less than the critical value for static recrystalisation, then grain grow after deformation will take place in the material (equation 6). After completion of the processes related to the recrystalisation may be austenite grain growth. In the case, when volume of recrystalisation is less than 1 (partial recrystalisation or non-full metadynamic recrystalisation) deformation is accumulated in material, and increasing volume of deformation in next step.

In order to determine the coefficients of equations Sellars model physical modeling was carried out using a metallurgical processes Gleeble 3800 simulator. The plasticity curves in the temperature range from 800 to 1200 °C and in the range of strain rates from 0,1 to 100 1 / s were determined. Based on the results of the plasticy curves, the peaks strain of dynamic recrystalisation were obtained. Exemplary plasticity curves are presented on figure 2. It can be found for the strain rate 0,1 1/s for both presented temperatures and for the strain rate 1,0 1/s for the temperature 900 °C the dominant mechanism is static recrystalisation. For other cases the dominant mechanism are dynamic and meta dynamic recrystallisation.



Fig. 2. Exemplary strain - stress dependency for the analyzed 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 Figure 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 was 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 were 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 its also be presented average diameter of the austenite former grain size obtained in laboratory tests and in the computer program based on the used model. In figure 4 there are presented microstructures of the samples deformed according to variants III and IV (table 1). When analyzing the data presented in Figure 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 fine-grained austenite is exceeding of peak deformation (e_{peak}=0.19) and dynamic recrystalisation 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 estimated difference not exceed 10 %. Future studies will address the topic represented by in reducing the the maximum error value below 10 %.

No of sample	Parameters of deformations (temperature, strain, strain rate) T [°C], , u [1/s]	Austenite former grain size µm		
		Test	Model	%
Ι	T_1 =1000, 1=0.9; T_2 =980, C_2 =0.3; u=1	12	11.2	6.7
II	T ₁ =1000, ₁ =0.6; T ₂ =980, ₂ =0.3; T ₃ =960, ₃ =0.3; u=1	10	10.5	5.0
111	$\begin{array}{llllllllllllllllllllllllllllllllllll$	18	21.	16.7
IV	$\begin{array}{llllllllllllllllllllllllllllllllllll$	40	37.1	7.5
V	$\begin{array}{llllllllllllllllllllllllllllllllllll$	28	25.9	7.2

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

Next stage of research was compare result form inmdustrial rolling proces of 5,5mm diameter wire rod of cold upsetting 23MnB4 steel grade with result obtained by developed model. The calculation of mictostructure of austenite grain size was made for parametrs of deformation presented in work [6]. The avege grain size of austenite after industrial rolling process was 28 m. For the same conditions of deformation averge grain size predicted by developed model was 25.5 m. Estimated results confirmed high accuracy of presented model for predictiom of austenite grain size in hot rolled boronium steels.

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 boronium steels 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.



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REFERENCES

- [1] SELLARS C. M. The Physical Metallurgy of Hot Working, in: Hot Working and Forming Processes, The Metal Society, London, 1980, pp. 3-15
- [2] MATSUDA H., BHADESHIA H. Avrami theory for transformations from non-uniform austenite grain structures, Materials Science and Technology, Vol. 19, 10, 2003, pp. 1130-1134
- [3] KLIMECKA-TATAR D., BALA H., LUSAREK B., JAGIELSKA-WIADEREK K. The Effect of Consolidation Method on Electrochemical Corrosion of Polymer Bonded Nd-Fe-B Type Magnetic Material. Archives of Metallurgy and Materials, Vol.54, No 1, 2009, pp. 247-256.
- KOCZURKIEWICZ B.: The model of prediction of the microstructure austenite C-Mn steel; Archives of Materials Science and Engineering, Volume 28, Issue 7, july 2007, p. 421÷424;
- [5] KUPCZYK J., LIS A.K.,KOCZURKIEWICZ B: Quantitative structural analysis of C. Mn. B steel cooled with different cooling rates; Proceedings of the 13th International Scientific Conference & Chievements in Mechanical and Materials Engineering+AMME 2005
- [6] LABER K., DYJA H., KALOMORZ M.: Analysis of the technology of Rolling 5,5 mm-Diameter Wire Rod of Cold Upsetting Steel in the Morgan Block Mill, Metalurgija, Vol.54, 2, 2015, pp. 415-418