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MATHEMATICAL MODEL OF STRUCTURE FORMING IN HOT-ROLLED SHEETS

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ABSTRACT

Time necessary for 95% metal recrystallization is modelled for the process of hot-rolling of sheets on a finishing train of continuous mills. The grain size of such a sheet is calculated for the different fractions formed as a result of a gradually accumulating hardening.

A comparison is made between the results of modelling and the corresponding experimental data for some rolled low carbon steels.

Key words: Hot-rolling of sheets, Recrystallization, Grain size, Rolled low carbon steel, Modelling of grain size

INTRODUCTION

A mathematical model is created for calculating microstructural changes in a low-carbon steel sheets exposed to hot rolling. The model is based on torsion investigations of grain size, published by other researchers and own experiments [1] for determination of grain size, carried out on a torsion machine under controlled loading. The material is a carbon steel produced in Kremikovtzi plant.

MATERIAL AND MECHANISM OF STRUCTURE FORMING

Material tested is a low-carbon steel Bulgarian Standard 2 КП (37.2 DIN) rolled on the finishing train of 1700 mill in Kremikovtzi plant, which consist of 6 continuous stands.

At hot rolling process an increase of deformation ε in some stands leads to a point of reaching its critical value, ε_m, for initiating nuclei of dynamic recrystallization [2, 3]. Since this moment the stress has become decreasing and the situation characterizes with a sufficient recrystallization. This process continues to establishment of equilibrium after deformation, described by ε_s. The equation of Zener-Hollamon presents an existing connection between the parameters of stress σ, strain rate v and metal temperature T by a specific characteristic z in (1), [4, 5]:

$$z = v\,exp\frac{Q}{RT} = A\,exp\,\beta\sigma\ , \tag{1}$$

where Q is activation energy of recrystallization during deformation process, R – universal gas constant, A and β – coefficients characterizing steel nature; and the parameter z expresses the influence of v and T on the energy stored in metal that makes recrystallization possible.

DISCUSSION AND MODELLING

Before the first stand (K1) of a finishing train, the semifinished-product grain size *d10* is usually accepted as equal to that before the rolling begins – *d00.* At the next stands it is necessary to calculate the time for metal recrystallization of 95%. So, after metal deformation in a given stand (K), that time named as *t95(K)* can be presented by (2):

$$t95(K) = \left[4.14 - 0.0035T_{exit}(K-1,N)\right]ln(\sigma - \sigma_0),\ [s]. \tag{2}$$

The size of already recrystallized grain is determined by (3) as a result from the deformation of a given point (N) situated along the semifinished product passing through stand (K):

$$dREX(K,N) = A(K,N)\left[14.9\,ln\frac{z}{8.510^9}\right]^{-\frac{2}{3}}\sqrt{\frac{d10(K-1,N)}{\varepsilon}},\ [\mu m], \tag{3}$$

where *A(K,N)* is a coefficient depending on steel nature at conditions (K), (N). At the same time the equation (3) represents our model of grain growth under classical recrystallization.

After the whole recrystallization of 95%, the grain size grows until the very beginning of deformation in the next stand. The time for this growth – *tREX(LK)*, calculated by (4), is a function of parameters as: distance between stands (LK), roll velocity *V,* and time *t95(K)* connected with a given stand, in this case (K):

$$tREX(LK) = \frac{LK}{V} - t95(K),\ [s]. \tag{4}$$

At semifinished-product rolling in the first stand (K=K1) of a finishing train with *n* stands, the time for metal recrystallization towards the back end (n >1) increases by the machine time τ_m for rolling on the continuous finishing train, (5):

$$tREX = tREX(LK) + \frac{L_n}{\tau_m},\ [s], \tag{5}$$

where L_n [m] is metal length.

The condition $tREX > 0$ means that between passes metal is wholly (95%) recrystallised. In such a case the size of grain already grown at a static recrystallization between passes *d10(K,N)* can be calculated. However the investigations show that the grain growth has different rate at metal temperatures over and below 900^0C.

At $T > 900^0 C$, the grain size *d10(K,N)* is represented by (6):

$$d10(K,N) = dREX(K,N) + 3.8710^{14} tREX \, exp \frac{-400}{RT + 273} . \qquad (6)$$

At $T \leq 900^0 C$, a condition characterizing continuous mills, the grain size *d10(K,N)* adopt the form of expression (7):

$$d10(K,N) = dREX(K,N) + 6.0210^{39} tREX \, exp \frac{-914}{RT + 273} . \qquad (7)$$

The condition $tREX < 0$ means that recrystallization between passes does not established wholly. During whichever next pass, a structure is formed that consists of recrystallized grains with sizes of *dREX(K,N),* and non-recrystallised ones – *dREX(K-1,N)* still with unchanged sizes equal to those before the previous pass.

This analysis shows that it can be accepted the following statement: the grains *dREX(K,N)* do not have residual stresses being wholly recrystallized, while the grains *dREX(K-1,N)* have residual stresses arisen from the previous pass. Then for the latter grains the stress in the rolled metal obtained during the pass (K+1) summarizes with that of the pass (K). Here we adopt the idea that each grain size has been studied independently by itself and not been influenced by the other grains. This approach is simplified and schematic, but there still exist many difficulties for describing structure forming at $tREX < 0$ including simultaneously both, recrystallized and non-recrystallized grains. It is important to note that at every next pass (under $tREX < 0$) the number of grains with different sizes doubles, a fact showing formation of complex structures corresponding to different residual stresses. This makes the algorithm for calculating different grain sizes very complicated.

For simplifying calculations it is necessary to make readings of sizes and relative parts taken of four grain-groups at the exit of the finishing train. Consequently, at $tREX < 0$ the readings made for the different (by size) grain-groups begin two passes before the exit of the train (K=Kn-1). Such a precision is enough for research and practice. Even if there we can find more than four grain-groups under $tREX < 0$ and before the pass (Kn-1), their corresponding relative parts will be negligible [1, 6].

We mark the size of recrystallized grain at the entrance of (Kn-1) stand as *dREX1*and the size of non-recrystallized grain after stand (Kn-2) as *dREX2.* Then we insert the following symbols: X1 for the corresponding relative part of recrystallized fraction *dREX1*; and X2 for the corresponding relative part of non-recrystallized fraction *dREX2.* All this results in (8, 9, 10, 11):

$$dREX1 = dREX(Kn-1, n); \qquad (8)$$

$$dREX2 = dREX(Kn-2,n); \tag{9}$$

$$X1 = 1 - exp\left(-2.996\frac{LK}{V}t95\right); \tag{10}$$

$$X2 = 1 - X1. \tag{11}$$

At the entrance of the last stand of train (Kn) four different grain sizes are calculated. The sizes of recrystallized grains are the already mentioned *dREX1*, and *dREX3* and *dREX4* with a common (summarized) corresponding relative part *X*3; *dREX3* forms from *dREX1* and *dREX4* – from *dREX2.* Then *dREX5* and *dREX6* are symbols for the grains formed from *dREX1* and *dREX2,* which are non-recrystallized until the metal enters the last stand. Their corresponding relative part is *X4*. The corresponding relative parts of the fractions *dREX3* –*dREX6* are *X*5–*X*8 respectively or:

$$X4 = 1 - X3;$$

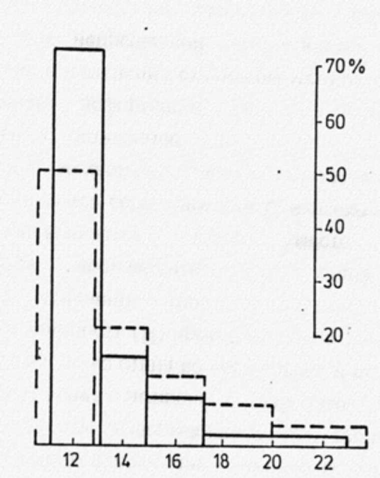
$$X5 = X1X3;$$

$$X6 = X2X3;$$

$$X7 = X1X4;$$

$$X8 = X2X4.$$

The histograms of grain sizes obtained experimentally and by the model are shown on Fig. 1. The experimental readings are done by automatic quantitative metallographic analysis.



Grain size, μm →

Fig. 1. Histogram of grain-size distribution for 4.0 x 1250 mm sheet of steel 2КП: the model data are shown by thick line and the experimental ones – by dash line

SUMMARY

The proposed model gives us possibilities for investigation of influence of different technological parameters and regimes on metal structure forming, then for control of structure forming during deformation process, and for design of new regimes for controlled sheet rolling.

REFERENCES

[1] T. Koinov, J.Kihara, Process Optimization for Hot Strip Mill, Trans. of ISI of Japan, **895-902**, (1986), Vol.26

[2] T. Koinov, D. Angelova, V. Mincheva, Bulgarian Journal of Metallurgy, **31-33** (1988), in Bulgarian

[3] T. Koinov, Tz. Tzankov, R. Shatalov, Rolling of Steel Sheets, Technika, Sofia, 279 pp, 1989, in Bulgarian

[4] H. Mecking, F. Kirch, Recrystallization of Metallic Materials, Cod. F. Haessner, Stuttgart, 2001

[5] B. Lifshitz, Metallography, Metallurgy, Moscow, 1971, in Russian

[6] M. Zaikov, V. Poluhin, A. Zaikov, H. Smirnov, Rolling Process, MIS&A Press, Moscow, 2003, in Russian