AUSTENITE-FERRITE TRANSFORMATION IN GRAIN-ORIENTED ELECTRICAL STEEL DURING HOT ROLLING

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Abstract

The austenite amount in grain-oriented electrical steel during hot rolling is very impotent parameter. It influences on structure and texture of hot rolling bands and on distribution and size of precipitations. In this paper austenite-ferrite ratio variation at high temperature (800-1300°C) was studied. There are two types grain-oriented electrical steel with different carbon contain were investigated. The research consists of two parts. First part is about calculating austenite volume fraction in grain-oriented electrical steel in high temperature. The calculation was carried out in program ThermoCalc. Second part is about physical experiments, which was provided on Gleeble 3800 system, optical and scanning electron microscopes. In this part specimens were heated up on several certain temperatures and then were quenched. The products of austenite decomposition (perlite or martensite) in metal were detected. In present research volume fraction of these products was determined and this volume fraction was assumed as amount of austenite at certain temperatures.

Keywords: grain-oriented electrical steel, hot rolling, austenite volume fraction, physical simulation

1. INTRODUCTION

Grain-oriented silicon steel is a soft magnetic material which is used as core materials of transformer. The main electrical properties of these steels are high magnetic induction and low core loss. In the iron the easiest direction of magnetization is <100> crystallographic direction. This steel is used in transformer, and magnetic properties have to be high only in one direction (rolling direction), and crystallographic texture {110}<001> (Goss texture) provides high magnetic properties in rolling direction. It grows during final annealing by secondary recrystallization (anomaly grain growth). Particles of secondary phase play one of the most important roles in this process - it inhibits normal grain growth.

The anomaly growth is a result of a long microstructure and texture inheritance chain [4]. Evolution of Goss texture starts at hot rolling stage [5]. In hot rolling sheet grains with Goss orientation locate in the sheet surface. Without this layer secondary recrystallization during final annealing will not be completed [1]. Also, inhibit precipitates distribution is generated at hot rolling stage. During slab reheating precipitates fully dissolve and then during hot rolling new precipitates nucleate and coarsen. So hot rolling is the operation which lays prerequisites for successful implementation of anomaly grain growth during final annealing [2].

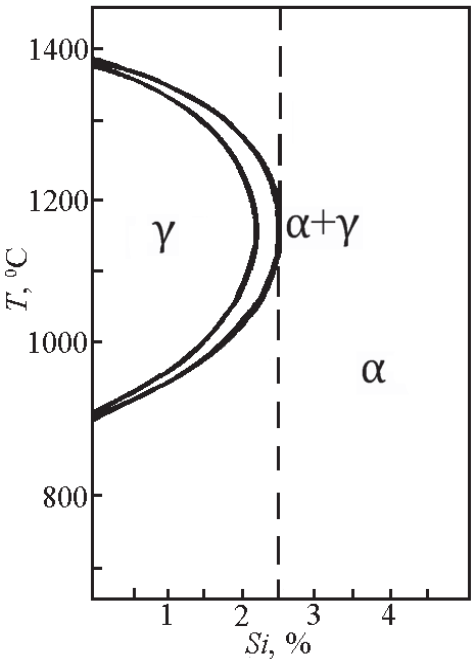


Fig. 1 Fe-Si phase diagram for alloys containing 0.01 to 0.02% C

Grain oriented electrical steel has about 3% Si and less than 0.04% of C. Such chemical composition allows to reduce austenite volume fraction in steel at high temperatures (**Fig.**

1) [3]. It's impotent parameter for texture behavior, structure and precipitation distribution in hot rolling sheet. Austenite volume fraction could be changed by increasing or decreasing of carbon content in steel.

In present research austenite volume fraction in grain oriented steel with different carbon contain was investigated. Results of physical simulation were compared with results of calculation data.

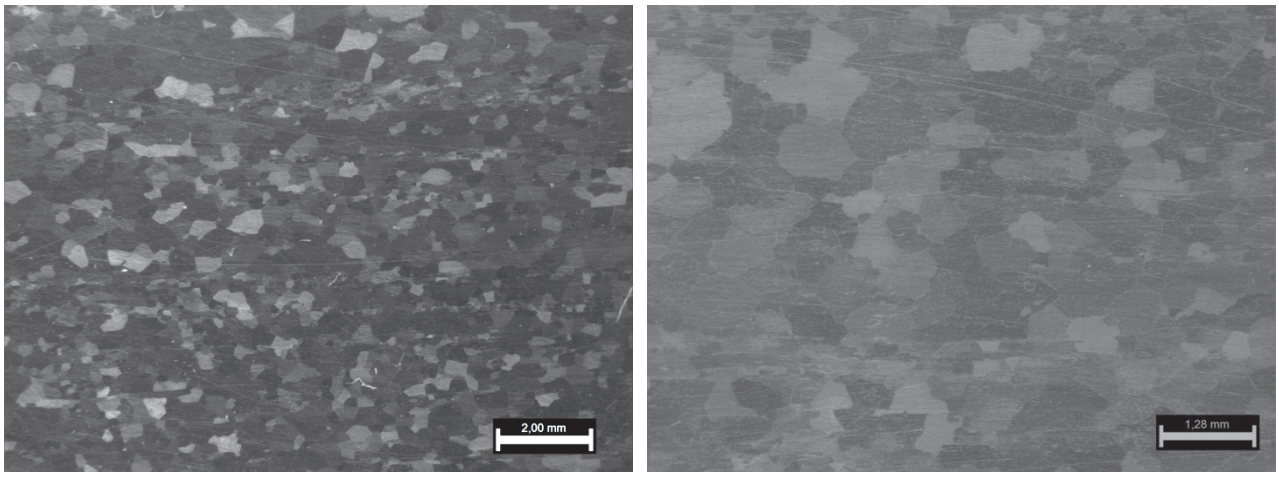
2. EXPERIMENTAL PROCEDURE

There are two types of grain oriented steel with different carbon content were investigated in present work. Specimens were cut from bands after rough rolling. Chemical compositions of steels used in present study are shown in **Table 1**.

Table 1 Chemical compositions of steels used in present study, wt %

Steel	Content of chemical elements											
	C	Mn	Si	P	S	Cu	Al	N	Ti	Sn	Cr	Ni
Type 1	0,035	0,31	3,2	0,012	0,004	0,52	0,15	0,01	0,002	0,01	0,02	0,01
Type 2	0,025	0,35	3,202	0,01	0,005	0,52	0,014	0,01	0,002	0,01	0,03	0,01

Initial structure of investigated steel is shown on **Fig. 2**. In Type 1 steel structure has equiaxed grains, the average grain size is about 200 μm. In Type 2 steel structure differs from Type 1 steel structure, the average grain size is about 1 mm. This difference could be explained by different carbon content which leads to different austenite volume fraction during rough rolling.



a) *b)*

Fig. 2 Initial structure of investigated steels: *a)* - Type 1, *b)* - Type 2

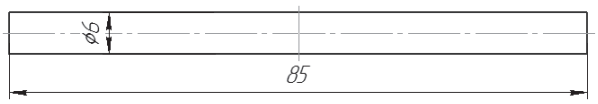


Fig. 3 Specimen geometry

Calculations were carried out in programs ThermoCalc, FactSage and MatCalc. The physical simulation was carried out on Gleeble-3800 system. Specimen scheme are submitted on **Fig. 3**. Specimens were heated up to certain temperatures from 700 ºC to 1250 ºC with heating rate 5 ºC/s, then were held 300 s and were quenched by water with maximal cooling rate (**Fig. 4**). Cooling consists of three parts (I, II and III in **Fig. 4**). The highest cooling rate in part I was reached with the help of

water quench. Water turns on and starts to flow in part II, and cooling rate is lower than in part I. Water finishes to flow in part III and cooling rate decreases. But this level of cooling rates was enough for structure fixation at high temperatures.

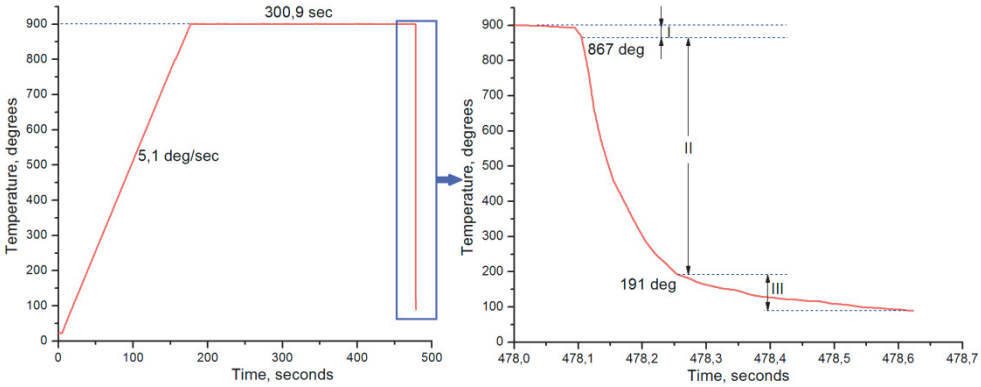
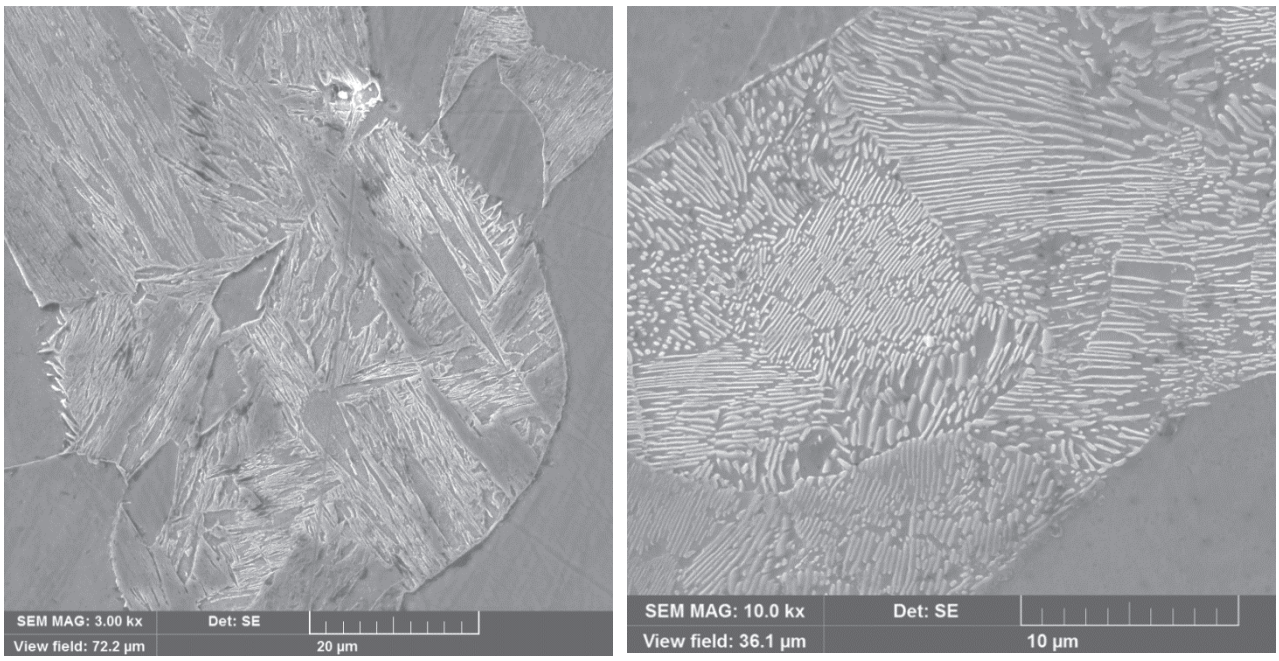


Fig. 4 Experiment scheme

Micros were prepared from specimen centers where thermocouples were welded. Structures were investigated on scanning electron microscope for phases identification. Also phases hardness was measured. Full structure panoramas were made by optical microscope. Austenite volume fraction was determined by measurement area of austenite decomposition products in program Thixomet PRO.

3. RESULTS AND DISCUSSION

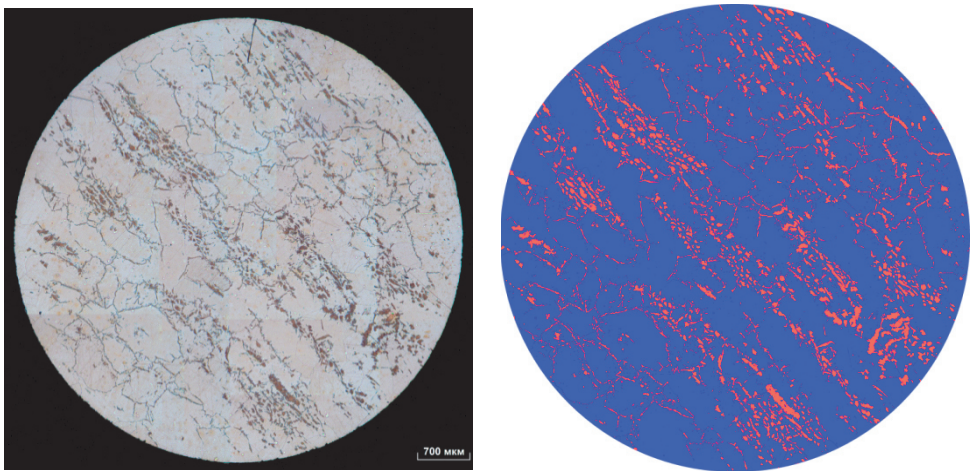
Products of austenite decompositions are shown on **Fig. 5**. There are two types of austenite decomposition products were identified - martensite (**Fig. 5, *a***) and perlite (**Fig. 5, *b***). In Type 1 steel only martensite was found, while in Type 2 steel martensite and perlite were detected, that could be explained by different carbon contain in steels. The ferrite matrix hardness is 200-230 HV_{200}, austenite decomposition products hardness is 330-370 HV_{200}.



a) *b)*

Fig. 5 Austenite decompositions in steel investigated: *a* - martensite; *b* - perlite

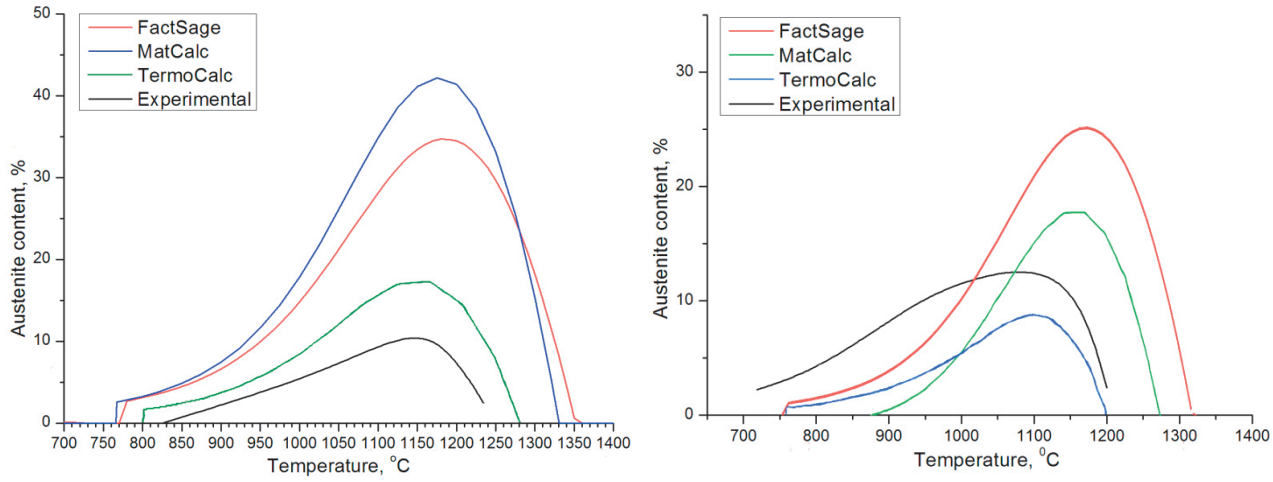
Panorama of specimen cross-section is shown on **Fig. 6, *a***. Such panoramas were made for every experimental point. Then analysis in order to determine martensite or perlite by color gradient (**Fig. 6, *b***) was performed. Value sets of austenite volume fraction for both steels were obtained (**Fig. 7**). Austenite volume fraction from temperature dependence was utilized, it shows good correlation with theory. Maximum amount of austenite volume fraction was determined for both carbon contents at the same temperature equal to 1150 ºC. Austenite exists in investigated steels in temperature range from 800 ºC to 1250 (1300) ºC. Lack of the maximum austenite amount reducing with decreasing of carbon content could be explained by small amount of experimental points for Type 1 steel.



a) *b)*

Fig. 6 Panorama of specimen cross-section

Results of physical simulation were compared with calculated values in different programs (**Fig. 7**). All graphs have similar behavior: temperatures of maximum austenite volume fraction, transformations start temperatures, transformations finish temperatures for each curves are close to each other. But in absolute value of austenite amount in Type 1 steel wide disagreement was found. It could be explained by small sample amount during experiment. By the other hand, in Type 1 steel difference between calculation values was found, that indicates the necessity of additional experiments.



a) *b)*

Fig. 7 Austenite volume fraction: *a* - Type 1; *b* - Type 2

Not uniform structure in thickness in hot rolling band plays impotent role in final properties of steel sheet formation. Austenite volume fraction has influence on this parameter, so structure formation could be controlled by austenite amount. Different temperature and deformation conditions of hot rolling result in certain austenite and the rest of phases content during hot treatment. Therefore, it is a way to manage magnetic properties of grain oriented silicon steels.

CONCLUSIONS

In present work austenite volume fraction in grain oriented silicon steels with different carbon contents during hot rolling was obtained and calculated. Calculations show good results in low carbon content case and worse results in high carbon content case. Maximum austenite amount was obtained at 1150 ºC, austenite exists in temperature range from 800 to 1250 ºC.

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