EFFECT OF TEMPER ROLLING ON THE STRAIN HARDENING OF A NON-ORIENTED ELECTROTECHNICAL STEEL

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Abstract
The present work deals about difference in strain-hardening at rolling with various rolling temperature (RT, 100°C, 250°C) of three samples (FC_1, FC_2, FC_3) from non-oriented electrotechnical steel. The study was performed by means of microhardness testing method. The sample which was rolled at room temperature has the most strain hardening below the surface, which relates with the current technological conditions in the rolling. When we rolled the samples at increased rolling temperature (100°C, 250°C), the most strain hardening is in the center of the sample which relates with the gradient of defromation trough the cross- section of material.

Keywords: microhardness, strain hardening, cold rolling, hot rolling

1 Introduction

Electrical steels play an important role in the generation, transmission, distribution and use of electrical power and are one of the most important magnetic materials. These steels are used mainly in electrically dependent on magnetic permeability and the losses due to eddy currents [1,2]. Electrical engines use a variable magnetic field, parallel to the sheet surface. For this kind of use, the ideal steel would be the non-oriented (NO) grain electrical steel with a texture component {100}<0vw>, that is, grains with planes {100} parallel to the sheet surface and <100> direction, so called „rotating“ cub texture [3,4].

The main properties of silicon steels, from a technological and scientific point of view, are depended on the microstructure and substructure i.e. grain size, grain morphology, density of crystallographic defect, preferable crystallographic orientation, chemical composition of the solid solution and presence of secondary phase particles [5].Taking into account the directional anisotropy of physical properties in crystallographic lattice of ferrite (bcc) and fact that NO steels are mainly used in circuit electromagnetic field, particularly in electrical motors as a core material, it is necessary to provide crystallographic isotropy in the plane of sheet in order to achieve good final magnetic properties [6].

Simultaneously with the characterization of deformed microstructure, study of deformation mechanism has evolved in order to explain precauses behind the changes of microstructure and texture during deformation. Change in orientation and shape of individual grains in polycrystalline material is caused by plastic flow due to generation of dislocations moving in certain direction (slip directions) within certain planes (slip planes). The progress of reorientation is gradual and leads to the development of texture or preferred orientation of the grains as well as a preferred shape change of the grains. Several crystal plasticity theories were developed to predict which slip systems are possible to operate and determine the resulting texture[7,8] .

It is well known, that the penetration of an indenter into a crystal or any other solid is accompanied by the appearance of high local stresses. In this case, all possible slip elements are activated, various interactions between dislocations take place, grain boundary movement [9-13]. It is important to note that crystallographic lattice of material is described by different slip systems in dependence of its orientation in space. It means that dislocation density value in grains change on value of applied deformation. The aim of this paper is to investigate difference in strain hardening trough the cross-section of material passed trough different rolling conditions.

2 Experimental material and procedure

Three samples (FC_1, FC_2, FC_3) from NO electrical steel that, taken from industrial line after cold rolling reduction with 74% of deformation and subsequent recrystallization annealing in laboratory conditions (800°C/10 min.),were used as experimental material. The annealing atmosphere was pure hydrogen (d.p.~ -23°C). The chemical conception of the experimental material was the same for each sample and is presented in **Tab.1**.

Table 1 Chemical composition of the investigated steel (in wt. %)

Material	C, %	Mn, %	Si, %	P, %	S, %	Al, %l	N, %
$FC_{1,2,3}$	0.006	0.24	1	0.07	0.009	0.013	0.011

The thickness of the investigated steel is d = 0.65 mm. After recrystallization annealing, all samples were rolled with 6% of deformation at various rolling temperatures. The sample FC_1 was rolled at room temperature (RT), FC_2 and FC_3 were rolled at 100°C and 250°C respectively. Microindentation method was used for determination of the strain hardening during rolling process. The microhardness measurements were performed on CSM Instruments (MHT) Micro-Hardness Tester with Berkovich indenter using standard indentation measurement method. The indentation parameters chosen from preliminary experiments were as follows: maximum load 10g, 10s hold at the maximum load and the Poisson's ratio was 0.33. The measurements for each sample were situated in the matrix 10 x 10 indentations equidistantly spaced in the x - axis by 20 μm and in the y - axis by 60 μm.

The mentioned indentation method was realized by means of Berkovich indenter for simplicity of measurement. Thus the results of microhardness were in HV values, because the classical Vickers hardness „HV“ and indentation hardness (Berkovich) „H_{IT}” are in correlation [14]:

$$HV = 0{,}0945.\ H_{IT}$$

3 Results and discussion

Each sample was divided trough the cross-section in to three areas (I., II., III.). Part I. represented the area from upper surface to about 180 μm, part II. represented the area from about

180 – 420 μm and part III. from about 420 – 600 μm (bottom surface). The averaged hardness values HV for samples (FC_1, FC_2, FC_3) were statistically measured in each of the predefined areas (I., II., III.) see **Tab.2**. The results were plotted graphically, as shown in **Fig. 1 – 3**.

Table 2 The hardness values (HV10) measured in the predefined areas of the samples FC_1, FC_2, FC_3

HV10 (rolling temperature)	Area of sample FC_1, FC_2, FC_3		
	I.	II.	III.
$HV10_{FC1}$ (RT)	289	276	286
$HV10_{FC2}$ (100°)	262	270	265
$HV10_{FC3}$ (250°C)	278	289	279

The result obtained from microhardness measurement HV10 on the sample FC_1, which was rolled at room temperature with 6% of deformation, is graphically denoted in Fig.1. As one can see, the strain hardening observed below the surface (I.) is higher than that measured in the center area (II.). It means that the rolling in the current technological conditions leads to occurrence of a non-uniform deformation distribution in the whole volume of deformed sample. This reveals in the highest intensity of deformation below the surface [15 - 17].

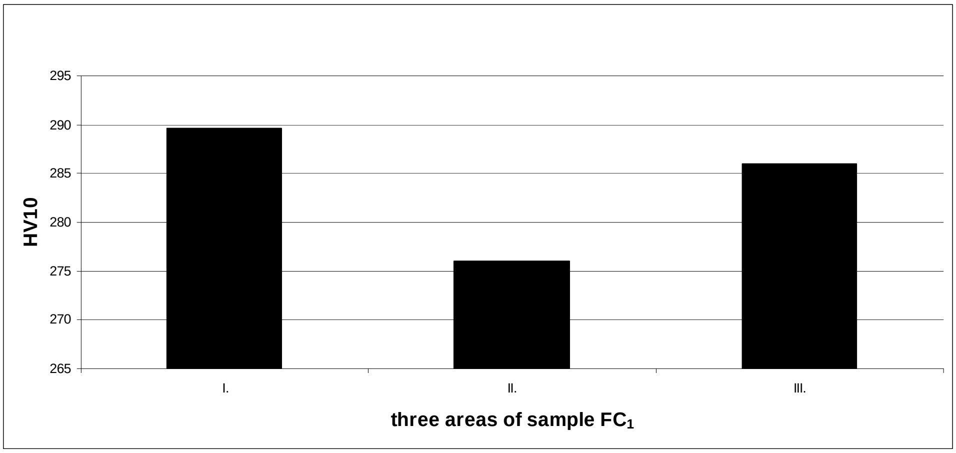

Fig.1 Difference in HV in terms of three sample FC_1 areas.

The sample FC_2 was rolled at 100°C rolling temperature with 6% of deformation. As one can conclude from Fig.2, the highest strain-hardening observed in the sample FC_2 was detected below the surface areas (I., III.). This behavior of strain hardening is opposite to that observed in the sample FC_1 cf. Fig. 1 and 2. This can be explained by the fact that there is a temperature gradient trough the cross- section due to the influence of cooling the sample on air. Hence, the temperature in the middle of the sample is higher than below the surface. The temperature effect causes decreasing the deformation resistance that in turn leads to higher intensity of deformation in the center of the sample in comparison to the surface and subsurface regions [15 - 17].

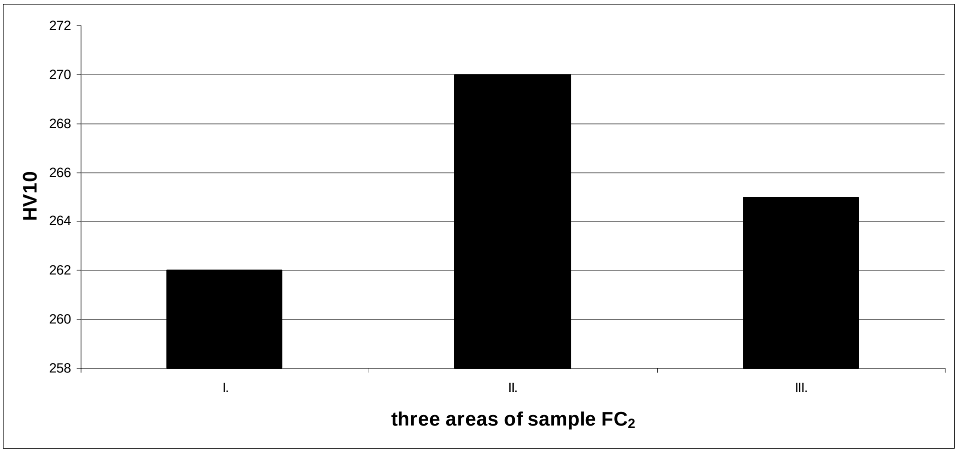

Fig.2 Difference in HV in terms of three sample FC_2 areas

The last sample was rolled at 250°C with 6% of deformation. Fig.3 describes the similar situation as that observed in sample FC_2, which was rolled at 100°C. Similarly to the previous case, the highest strain hardening is detected in the center of the sample. The hardness HV10 of the sample FC_3 increased by about 4 % of HV10 values in comparison to that measured in the sample FC_2, cf. Figs. 2 and 3.

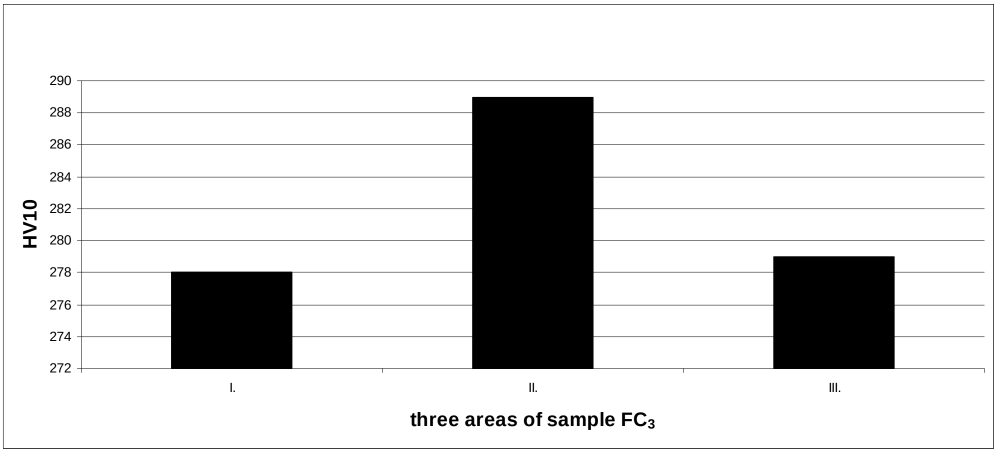

Fig.3 Difference in HV in terms of three sample FC_3 areas

Concluding the aforementioned results one can say that, with increasing of rolling temperature, the deformation resistance decreases and increases the intensity o deformation in the center of the sample. Moreover, there was observed an increase of hardening in the center at rise of temperature from 100°C to 250°C.

4 Conclusions

The difference in strain hardening in three equal samples (FC_1, FC_2, FC_3) for non-oriented electrical steel was investigated by microindentation method with measuring microhardness

HV10. It was showed that the sample, which was rolled at room temperature (FC_1) had the higher strain-hardening below the surface than that observed in the cross section center area. A reverse situation occurred when the samples (FC_2, FC_3) were rolled at increased rolling temperature (100°C, 250°C). Here, the strain hardening of the samples in the cross section center was much higher than that below the surface of the samples. Thus it means that the temperature gradient effect causes decreasing the deformation resistance and in the same time increasing the intensity of deformation in the center of the sample.

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