UKRAINIAN JOURNAL OF MECHANICAL ENGINEERING AND MATERIALS SCIENCE
Vol. 8, No. 4, 2022

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DETERMINATION THE CAUSES OF PREMATURE DESTRUCTION OF SHEET ELECTRICAL STEEL

Received: September 2, 2022 / Revised: September 14, 2022 / Accepted: September 30, 2022

https://doi.org/10.23939/ujmems2022.04.041

Abstract. Sheets of electrical steel are produced by hot and cold working by pressure (mainly by rolling). In this case, the load during rolling should be chosen in such a way as not to impair the electrical properties of the steels. Received two sheets of electrical steel from different production batches. One of the sheets of electrical steel is prematurely destroyed at the stage of machining parts for electrical transformers. It has been established that an increased content of phosphorus worsens the characteristics of plasticity, which can complicate the process of pressure treatment in the manufacture of sheet electrical steel. Macrostructural analysis revealed longitudinal lines due to rolling. In places of greatest deformation, perpendicular to the direction of rolling, there are cracks and chipping of the insulating layer. Microstructural analysis showed that the cracks formed in the process of rolling sheet electrical steel propagate to a depth of 1.5–2.0 µm. The presence of linear depressions in the structure of the sheet steel indicates that the critical overload has been exceeded during rolling. The increased microhardness in samples of electrical steel is explained by the increased concentration of macro- and microstructural defects formed during the rolling process. It has been established that the main reasons for the premature destruction of electrical steel sheets are an increased content of harmful impurities and incorrectly selected pressure treatment modes, leading to the formation of macrocracks.

Keywords: microstructure, electrical steel, microhardness.

Introduction

In recent years, the domestic non-oriented electrical steel production capacity quickly improving, the market competition is becoming increasingly fierce and the profit space is increasingly narrow. Manufacturers to get more living space is trying to improve product quality and reduce the production costs to improve the competitiveness of enterprises in the market.

Electrical sheet steel has received the greatest application in electrical engineering. This steel is an alloy of iron with silicon, the content of which in it is 0.8 – 4.8 % and impurity elements. Silicon is introduced into iron in the form of ferrosilicon (an alloy of FeSi with iron) and is present in it in a dissolved state [1–6]. Silicon reacts with a more harmful (for the magnetic properties of iron) impurity – oxygen, reducing iron from its FeO oxides and forming silica SiO_2, which partially passes into slag. Silicon also contributes to the release of carbon from Fe_3C (cementite) with the formation of graphite. Thus, silicon deprives the chemical compounds of iron (FeO and Fe_3C), which cause an increase in the coercive force and increasing hysteresis losses. In addition, the presence of silicon in iron in an amount of 4 % or more increases the electrical resistivity compared to pure iron, resulting in reduced eddy current losses. Such a complex of chemical interactions of silicon leads to an increase in the probability of the formation of defects in the structure of electrical steel [7–11].

Sheets of electrical steel are produced by hot and cold working by pressure (mainly by rolling). In this case, the load during rolling should be chosen in such a way as not to impair the electrical properties of the steels [12–14].

The quality of finished non-oriented electrical steel is an integral parameter that includes magnetic properties, surface quality (appearance, electrical insulation coating resistance coefficient, adhesion) and other consumer characteristics. One of the most common surface defects is the “oxidation in the form of bands” defect [15–17].

Problem Statement

Received two sheets of electrical steel from different production batches. One of the sheets of electrical steel is prematurely destroyed at the stage of machining parts for electrical transformers. Therefore, the purpose of this work is to establish the causes of the destruction of the material of sheet electrical steel.

Main Material Presentation

Experimental Approach. To achieve the goal of the work, 4 samples for research were made (Table 1).

Table 1

Marking of manufactured samples for research

Sample No.	Description of samples
1 – A sheet of electrical steel that collapses during the technological process of manufacturing parts of electrical transformers	
1.1	Samples cut transverse to sheet 1 rolling direction
1.2	Samples are cut along to sheet 1 rolling direction
2 – Sheet of electrical steel that does not collapse during the technological process of manufacturing parts of electrical transformers	
2.1	Samples cut transverse to sheet 2 rolling direction
2.2	Samples are cut along to sheet 2 rolling direction

Macroanalysis was performed using an MBS-9 microscope. The macrostructure was documented using an eyepiece camera LCMOS14000KPA.

The determination of the elemental composition [18] by X-ray fluorescence analysis was carried out on an X-ray spectrometer SER-01 “ElvaX Light” [19]. ElvaX Light SER-01 (Fig. 1) is a modification of the ElvaX spectrometer with an extended range towards light elements.

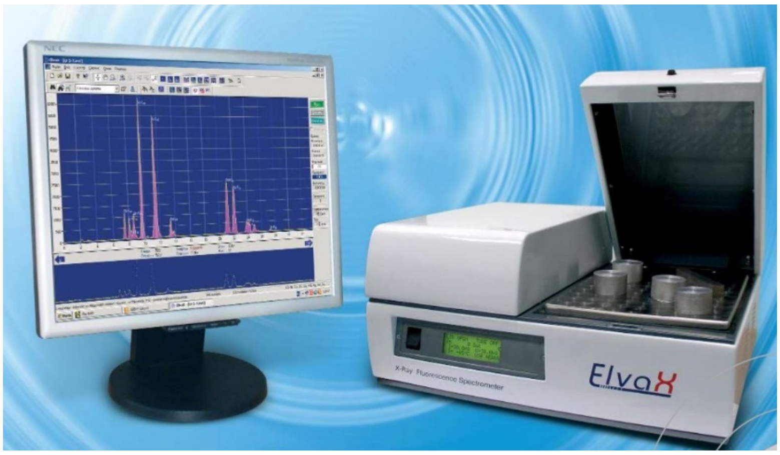


Fig. 1. X-ray spectrometer SER-01 "ElvaX Light" [19]

To detect the microstructure, the samples were placed in aluminum tube mandrels and fixed in the desired position with EDP-5 epoxy resin. After polishing, the microsections were examined using a MICROTECH® MMT-14Ts optical metallographic microscope at a magnification from ×100 to ×500; microstructures were documented with an eyepiece camera LCMOS14000KPA; processed images from a digital camera software ToupView [20, 21].

Investigations of the microhardness of coatings after annealing on NOVOTEST TC-MKV1 Microhardness testers. The principle of operation of this device is identical to the principle of operation of the Vickers hardness tester [22].

To establish the content of harmful impurities, a study of the elemental composition of electrical steel was carried out. The results of elemental analysis are presented in table. 1. Sample No. 1 (with flaws) and No. 2 have almost the same content of Cu and S impurities. The content of the main alloying element Si in sample No. 1 is 33 % higher than in No. 2. Also in this sample No. 1 is 56 % more Mg and 41 % more P than billet No. 2. The increased content of phosphorus in sample No. 1 worsens the ductility characteristics, which can complicate the process of forming in the manufacture of electrical steel sheet.

Table 2

Elemental composition of the electrical steel sheets

Sample No.	Concentration, at. %					
	Si	Mg	Cu	P	S	Fe
1	3.68±0.04	1.23±0.05	0.47±0.02	1.00±0.02	0.02±0.004	the rest
2	2.45±0.03	0.54±0.04	0.48±0.02	0.59±0.032	0.03±0.004	the rest
* Note: Carbon was not determined						

Macrostructural analysis on sample No. 1 revealed longitudinal lines due to rolling (Fig. 2, *a*, *b*). In places of greatest deformation, perpendicular to the direction of rolling, there are cracks and chipping of the insulating layer (Fig. 2, *b*). No macrostructural defects were found on samples of sheet electrical steel No. 2. The presence of macrostructural defects in sheet electrical steel No. 1 can be explained by incorrect rolling conditions and/or an increased content of phosphorus and magnesium.

The microstructure of sheet electrical steel was studied on polished samples, which were cut in transverse and parallel directions relative to the rolling direction.

Sample No. 1.1 has a microsection plane located across the rolling. It contains a large number of non-metallic inclusions (Fig. 3, *a*, *b*). On sample No. 1.1, there are depressions located along the rolling to a depth of 55–60 µm (Fig. 3, *a*). There is a thin 2.0–10.0 µm insulating coating on the sample surface.

The number of non-metallic inclusions in sample No. 1.2, located along the rolling, visually looks much less (Fig. 3 *c*, *d*). From the surface, the sample has cracks with a depth of 1.0–2.0 μm.

On samples No. 2.1 and No. 2.2 (along and across the rolling, respectively), the surface is without cracks (Fig. 4), non-metallic inclusions are almost absent (Fig. 4, *b*, *d*), the thickness of the insulating coating – 1.0–2.0 μm (Fig. 4, *b*).

Thus, the microstructural analysis showed that the cracks formed in the process of rolling sheet electrical steel propagate to a depth of 1.0–2.0 μm. The presence of recesses in the structure of the sheet steel indicates that the critical overload has been exceeded during rolling. This could cause premature destruction of steel in the process of further machining.

Microhardness was measured with a NOVOTEST TS-MKV1 hardness tester at a load of 0.49 N on transverse microsections that cut out across and along the rolling of electrical steel sheets (Table 2). Samples No. 1.1 and No. 1.2 with macrostructural defects have approximately the same hardness 195–206 HV across and along the rolling. Sample No. 2 (2.1 and 2.2) has a hardness that is nearly 30 % greater along the rolling (HV 217) versus that across the rolling (HV 165), i.e. sample No. 2 has an anisotropy of properties.

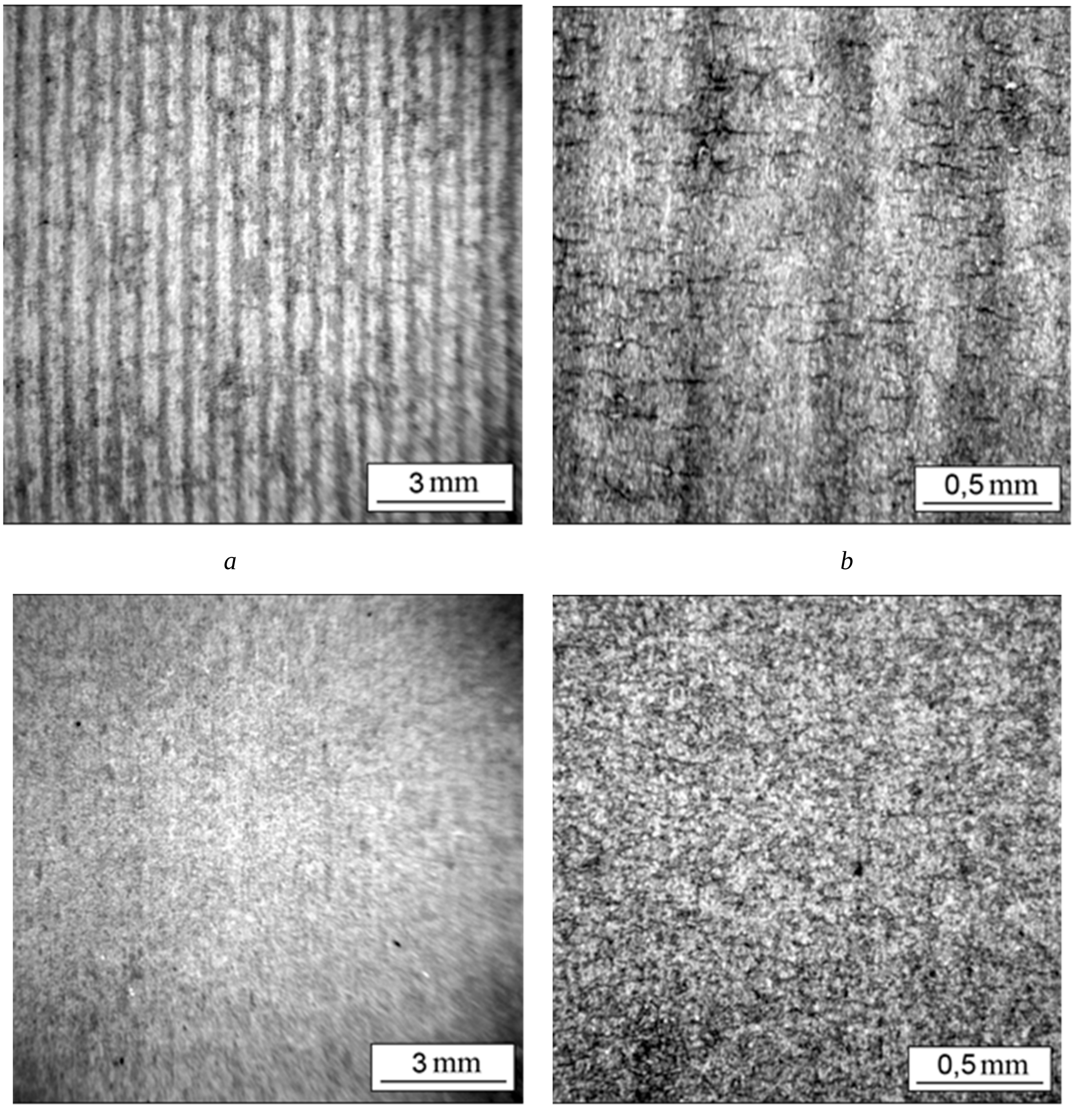
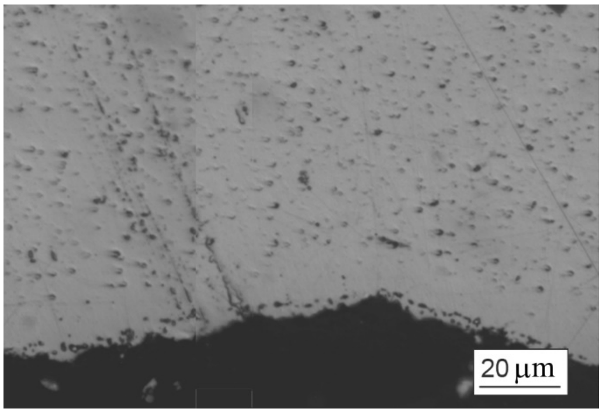


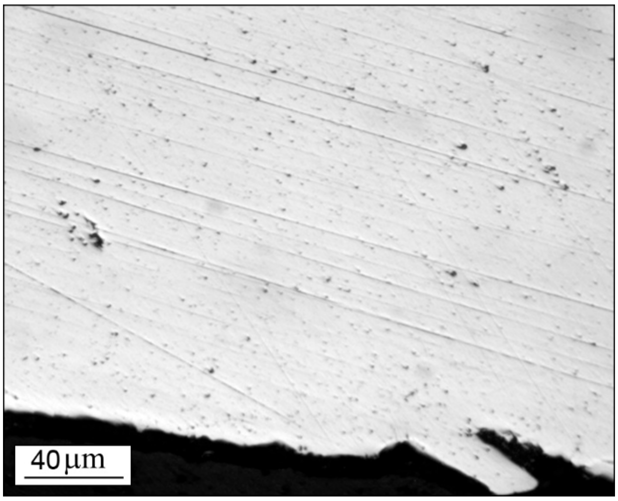
Fig. 2. Macrostructure of sheet electrical steel: a, b – sample No. 1; c, d – sample No. 2

The increased microhardness of the electrical steel sample No. 1.1 is explained by the increased concentration of macro- and microstructural defects formed during the rolling process.

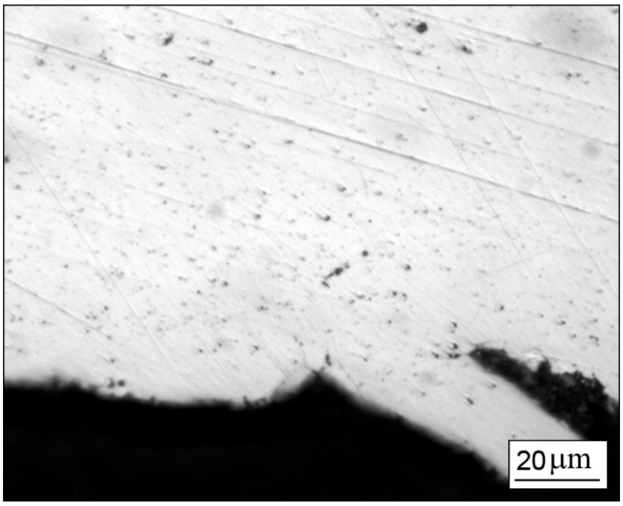
a



b



c



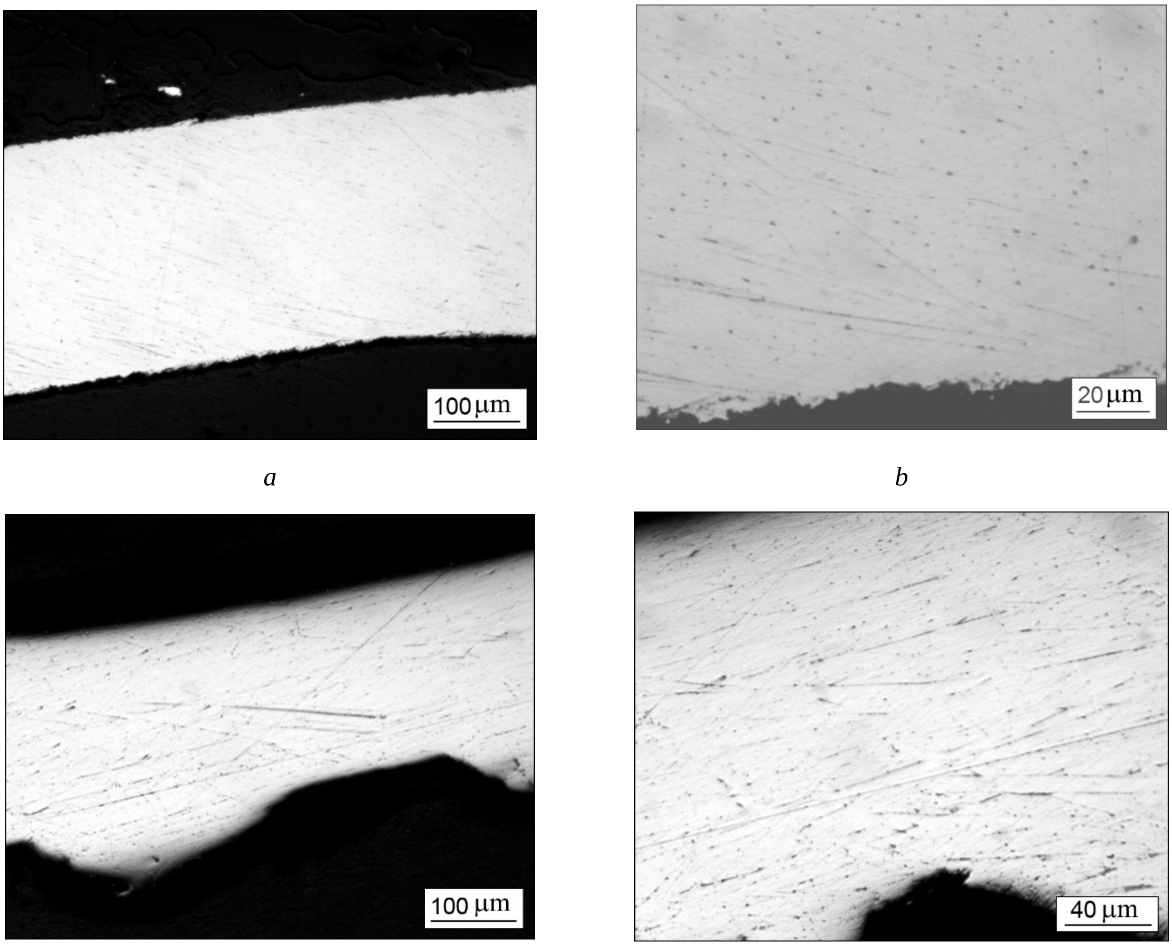
d

Fig. 3. Microstructure of electrical steel as polished state, sample No. 1:
a, b – sample No. 1.1; c, d – sample No. 1.2

Table 2

Microhardness of the electrical steel sheets

Sample No.	d_1, µm	d_2, µm	Microhardness (hardness tester), HV	Microhardness (calculated values), HV
1.1	21.50	21.25	202.8	206.2
	23.00	21.50	187.1	
	20.25	20.00	228.7	
1.2	21.75	22.25	191.4	195.2
	21.25	21.25	205.1	
	22.25	22.00	189.2	
2.1	23.25	23.75	167.7	165.3
	24.5	23.00	164.2	
	23.75	23.75	164.2	
2.2	20.00	19.25	240.5	217.2
	21.00	20.50	215.2	
	22.25	21.25	195.8	



a *b* *c* *d*

Fig. 4. Microstructure of electrical steel as polished state, sample No. 2:
a, b – sample No. 2.1; c, d – sample No. 2.2

Thus, it has been established that the main reason for the premature destruction of electrical steel sheets is an increased content of harmful impurities and incorrectly selected pressure treatment modes, which provoke the formation of macrocracks.

Conclusions

The increased content of phosphorus in electrical steel (sample No. 1) worsens the ductility characteristics, which can complicate the process of pressure treatment in the manufacture of electrical steel sheets.

Macrostructural analysis revealed longitudinal lines due to rolling. In places of greatest deformation, perpendicular to the direction of rolling, there are cracks and chipping of the insulating layer.

Microstructural analysis showed that the cracks formed in the process of rolling sheet electrical steel propagate to a depth of 1.0–2.0 μm. The presence of linear depressions in the structure of the sheet steel indicates that the critical overload has been exceeded during rolling.

The increased microhardness of the electrical steel (sample No. 1.1) is explained by the increased concentration of macro- and microstructural defects formed during the rolling process.

The main reasons for the premature failure of electrical steel sheets are an increased content of harmful impurities and incorrectly selected pressure treatment modes, leading to the formation of macrocracks.

Acknowledgements

In memory of Sergiy G. Shvachko (30/08/1963 – 25/05/2022) – senior teacher of the department Materials Science and Engineering. Lviv Polytechnic National University.

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