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EVALUATION OF MICROSTRUCTURE AND MECHANICAL PROPERTIES OF FERROMAGNETIC STRUCTURAL MATERIALS USING BARKHAUSEN NOISE

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1. INTRODUCTION

Magnetic Barkhausen noise (MBN) analysis [1] is regarded as a non-destructive technique for considerable significance in microstructural characterization of ferromagnetic materials. Manufacturing industry spends a lot of effort in determining and ensuring the desired microstructure of steels. In practice, the microstructure is usually determined by metallographic techniques and hardness test where certain regions of the representative samples can be taken into account [2]. Because application of these methods is time consuming and quite expensive, there is an interest to develop a cheap non-destructive techniques capable for rapid inspection of material state.

2. EXPERIMENTAL PROCEDURE

In the present study, magnetic Barkhausen noise and Vickers hardness measurements were performed to investigate the relationship between the magnetic properties and microstructure of structural steel.

Magnetic tests were carried out using the MEB-4C defectoscope. The measuring head consisted of a U-shaped core of electromagnets wrapped in a wound excitation coil. The pick-up coil was built into the sensor. A triangular waveform was applied. In the pick-up coil, a voltage signal U_0 was induced. To estimate the intensity of the Barkhausen noise, the fast-variable component of U_0 was separated by means of a high-pass filter f = (0-500)Hz. Analysis of this component provided information on the samples' material structure.

The envelopes of Barkhausen noise were calculated as rms value U_b according to the equation [1]:

$$U_b = \sqrt{\frac{1}{\tau}\int_0^{\tau} U_{tb1}^2(t)dt} \tag{1}$$

where U_b [V] is the root mean square of the coil output voltage; U_{tb1} [V] is the fast-variable component defining voltage separated by means of the high-pass filter from induced voltage in the pick-up coil, and τ [s] is the integration time.

In the next step, the parameter amplitude of Barkhausen noise (Ub_{pp}) defined as the voltage difference between the maximum peak value of the magnetic Barkhausen noise (U_b) and the background noise (U_{tb}) was determined.

A subsequent important parameter, the integral of the half-period voltage signal of MBN was also calculated.

$$Int(Ub) = \int_{-Ugmax}^{+Ugmax} U_{sb} dU_g \tag{2}$$

where:

$$U_{sb} = \sqrt{U_b^2 - U_{tb}^2} \tag{3}$$

U_{sb} [V] - root mean square of Barkhausen emission voltage after correction due to background noise,
U_b [V] - root mean square of the coil output voltage,
U_{tb} [V] - root mean square of background voltage.

The microstructure of the tested materials was analysed using an Olympus PMG 3 light microscope. Vickers hardness (HV 3) was measured by means of universal Duramin-500 Struers hardness tester. The Vickers hardness values were converted onto the Brinell hardness [3] in order to assess the ultimate tensile strength [4], tab. 1.

3. RESULTS

Typical envelopes of the Barkhausen noise are presented in Figs. 1-3 and the corresponding microstructures of the samples in Figs. 4-6.

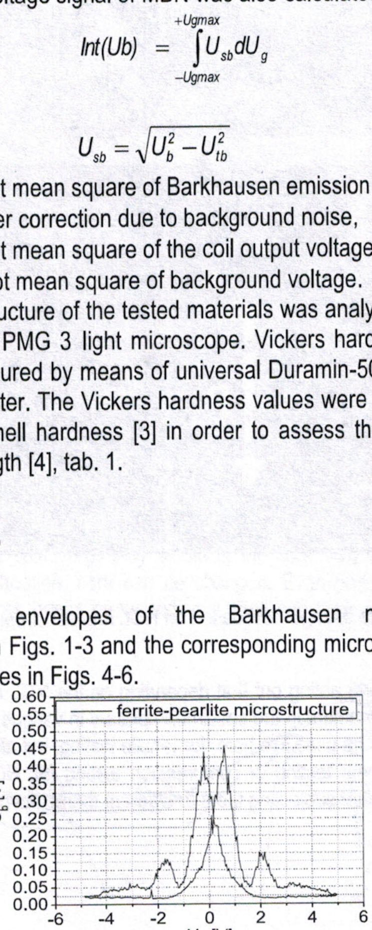

Fig. 1. The Barkhausen noise envelope coming from ferrite-pearlite microstructure (sample No. 1)

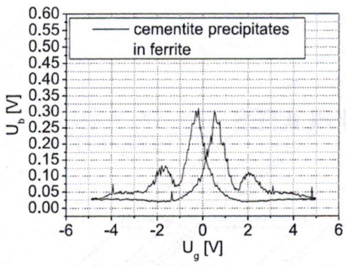

Fig. 2. The Barkhausen noise envelope coming from ferritic microstructure with precipitations of cementite (sample No. 2)

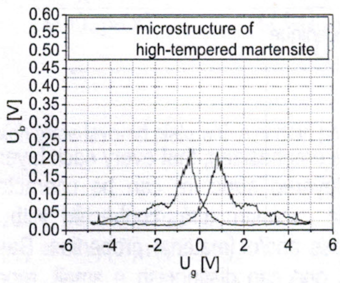

Fig. 3. The Barkhausen noise envelope coming from microstructure of high-tempered martensite (sample No. 3)

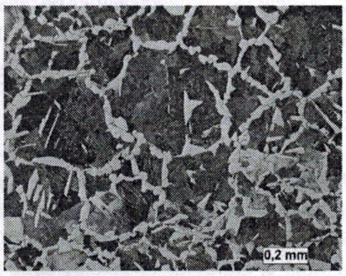

Fig. 4. Ferrite-pearlite microstructure in sample No. 1

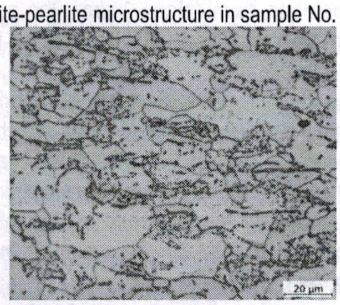

Fig. 5. Ferritic microstructure with precipitations of cementite in sample No. 2

Table 1 presents the results of hardness and non-destructive tests. It was oberved that the values of mechanical parameters increase with the reduction of the amplitude and integral value determined from the envelope of Barkhausen noise. The shape of MBN depends on type and volume of structural phases in the material. The first two samples tested have two structural phases, so two peaks in MBN envelope were observed. The first of them is related to the presence of ferrite in both samples (No. 1 and No. 2).

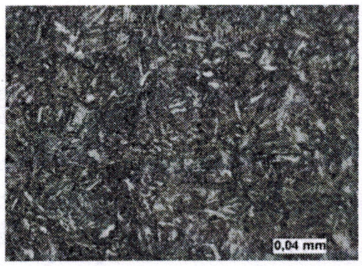

Fig. 6. Microstructure of high-tempered martensite in sample No. 3

The second maximum is related to structural phase containing carbon in its chemical composition. In the case of sample No. 1, the structural phase containing carbon is perlite, whereas in the case of sample No. 2 – cementite. The sample No. 3 has the structure of high-tempered martensite, it contains small cementite particles in the fine grained ferritic matrix. The dense distributed cementite particles can be treated as the significant obstacles for domain walls, therefore, this sample is characterized by the lowest MBN noise parameters.

Tab. 1. The results of destructive and non-destructive tests for the three various types of microstructure

Physical quantity	ferrite-pearlite	cementite precipitates in ferrite	high-tempered martensite
HV3 / HBW [MPa] [3]	212 / 200	157 / 152	302 / 284
$R_m \approx 3.5$ HB [MPa] [4]	700	532	994
Ubpp1 [V]	0.45	0.30	0.23
Ubpp2 [V]	0.15	0.11	0.08
Int(Ub)1 [V²]	0.44	0.21	0.21
Int(Ub)2 [V²]	0.052	0.036	0.045

4. CONCLUDING REMARK

The Barkhausen noise method can be used to assess the microstructure and estimate the mechanical properties of ferromagnetic materials.

ACKNOWLEDGMENTS

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REFERENCES

1. **Jiles D.** (1998), *Introduction to magnetism and magnetic materials*, Taylor and Francis Group, New York.
2. **Błażewski S., Mikoszewski J.** (1981), *Measurements of metal hardness*, WNT, 1981, 443 pages (in polish).
3. **Franco F.A., González M.F.R., de Campos M.F.** (2013), *Relation between magnetic Barkhausen noise and hardness for Jominy quench tests in SAE 4140 and 6150 steels*, Journal of Nondestructive Evaluation, Vol. 32, 93-103.
4. Conversion table for hardness for Vickers, Brinell and Rockwell scales, Metalogis, 1 page (in polish).