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SEPARATION STEEL PARTS WITH DIFFERENTE MICROSTRUCTURE USING BARKHAUSEN NOISE ANALYSIS

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Abstract

Among different nondestructive magnetic methods, barkhausen noise is a new one in evaluation of metallurgical and mechanical properties of ferromagnetic materials such as grain size, hardness and microstructure assessment as well as determination of residual stresses. The basis of the method is on the abrupt motions and rotation of domian walls in ferromagnetic materials, when magnetized under AC current. Difference in magnetic properties, due to variation in microstructure, results in the different behavior under magnetization. Barkhausen noise is related to materails magnetization behavior, which in turn, may be used to separate various microstructures. In this research, analyzing barakhausen signals, different microstructures due to the varrious heat treatments (annealing, normalizing, quenching and quench-tempering at different temperatures) were examined. The comparsion were made for position and ampliutede of the MBN peaks in the voltage-magnetic field strength diagram. The results indicate the BN technique can be succsessfully used to separate the microstructures.

Keywords: *Nondestructive test; Barkhausen noise; Microstructure; Heat treatment;*

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Introduction

Magnetic materials consist of a patchwork of magnetic domains where all the magnetic moments in a particular domain point in the same direction, usually an easy axis of the crystal. When a changing magnetic field is applied, the walls separating the domains move so that domains aligned close to the field direction grow at the expense of those that are less aligned. The movement occurs in a series of sudden jumps as the domain walls break away from pinning sites such as dislocations, precipitates and grain boundaries. This leads to corresponding jumps in the magnetization of the material, known as magnetic Barkhausen noise. If a search coil is wound on a specimen and connected to an oscilloscope, irregular spikes will be observed on the voltage-time curve. These voltage spikes are known as Barkhausen noise (BN) [1].

In recent decades extensive research on application of the barkhausen noise signals as a new method of non-destructive testing is performed. Ferrite- Martensite steels Characterization by analyzing the peak intensity and the magnetic field required to create a peak, has been done by Klbeber and et.al in 2003 [2,3]. Ferreira and et.al used of magnetic barkhausen noise analysis for nondestructive determination of stresses in structural elements [4]. Assessment of structural ductile iron and study on mechanical and magnetic properties of plain carbon steels with using voltage-magnetic field diagram, from output data of barkhause noise signals, is done [5]. Determine the depth of the surface has been hardened, as for the presence difference in magnetic properties of martensite and ferrite-pearlite structures [6,7]. Evolution the rate of the of pearlite spheroidization and the amount of residual stresses is other topics reviewed by the same method [8,9].

In this study, separated specimens with different microstructure resulting from various heat treatment, with analysis on barkhausen noise signal parameters, as peak intensity and peak position in applied magnetic field, were done.

2. Experimental

2.1. Material and Heat Treatment

AISI 1045 steel rods are used in this study. The chemical composition of the specimens is shown in Table 1. Eight cylindrical specimens of 30 mm in diameter and 150 mm in length were prepared. In order to manufacture specimens with difference microstructure, various heat treatments**,** Annealing, Normalizing, quench and quench-temper were done. Table 2 shows heat treatments and temper temperature. Microstructures were characterized using conventional methods: metallography and hardness measurement.

Table 1. Chemical composition of AISI 1045

Elemnts	C	Si	S	P	Mn	Fe
Wt%	0.44	0.24	0.02	0.004	0.57	remain

Table 2. Heat Treatments

Specimen No.	Heat Treatment	Cooling methode	Temper temperture and time temper
1	Anneal	furnace cooling	–
2	Normalized	Air	–
3	Quench	Water-slat10%	–
4	Quench-temper	Water-slat10%	120 min-200 ˚C
5	Quench-temper	Water-slat10%	120 min-300 ˚C
6	Quench-temper	Water-slat10%	120 min-400 ˚C
7	Quench-temper	Water-slat10%	120 min-500 ˚C
8	Quench-temper	Water-slat10%	120 min-600 ˚C

* austenitization at 880˚C for 60 min

2.2. Barkhausen Noise Measurements

The BN measurements were made using equipment developed in the authors' laboratory. The testing procedure was developed to give a high degree of reproducibility, i.e. to produce minimum variations in the results in a run of tests on the same specimen. A schematic illustration of the equipment is shown in Fig. 1. All experiments with the optimization of parameters such as frequency and range of signal filtered were done. Optimal frequency of 2Hz for this review was considered. The magnetic field is applied to the specimens using a U-shape core with a 850 turns coil wound around it. In order to increase the intensity of the magnetic field applied to the specimen, the output signal is amplified by an amplifier. A fixed rate of magnetization was imposed on the specimen with the greatest of care in order to ensure a perfect reproducibility of the measurements. The magnetic Barkhausen noise is detected through a 350 turns coil wound around a Polyvinylchloride (PVC) support. The induced voltage is pre-amplified (100x), passed through a band-pass filter (3-200KHz) and finally digitized by an oscilloscope card in a PC. The data was acquired and analyzed using TNM software.

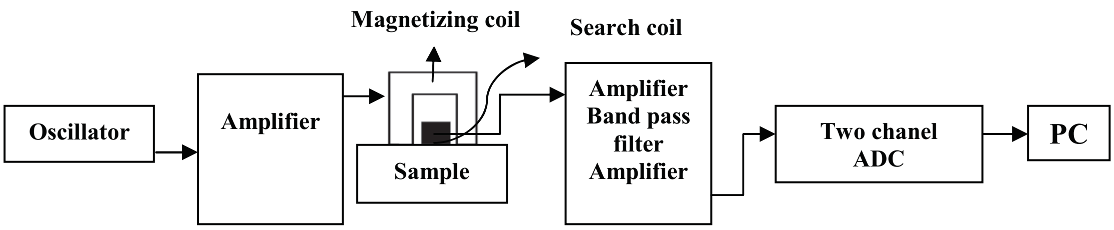


Figure 1. Schematic illustration of magnetic Barkhausen noise apparatus

Result and discussion

Metallographic and hardness examination

Fig. 2 indicates optical microscopic image of a microstructure in a cross section of an specimen No. 1, 2, 3 and 8. Table 2 presents the results Vickers hardness measurement of the specimens in terms of average. As it is shown, microstructure of the specimen annealed is more coarse-grained than specimen normalized, so density of grain boundaries is less. However these microstructures (ferrite-pearlite) are quite different with microstructure of quenched and tempered specimens. In the quenched specimen martensitic microstructure is evident. With increasing temperature, the structure is getting out from needle state and hardness is reduced.

Barkhausen Noise Measurements

Assessment BN signals at five frequencies, 0.5, 1, 1.5, 2 and 5 Hz was performed. According to the results, the frequency changes does not significant effect on results, however, due to the elimination of eddy currents that may occur due to changes in the applied magnetic field, low operating frequency is selected. By Origin Pro8 software an equivalent diagram for BN signals obtained, were plotted. Some of these diagrams are shown in Figure 3. Figure 4 shows BN signals parameter for specimens with different microstructures.

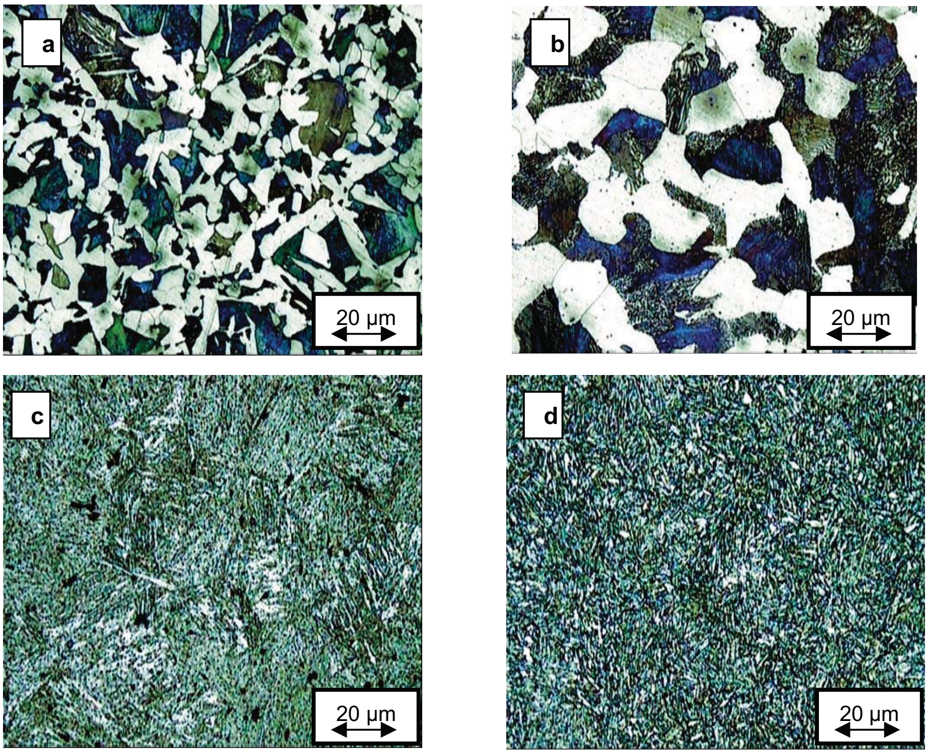


Figure 2. Microstructure of specimens (a) Annealed (b) Normalized (c) Quenched (d)Quench-temper (600˚C)

Table 2. hardness measurement

Specimen No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Hardness (VHN)	**150**	**180**	**650**	**545**	**460**	**340**	**280**	**236**

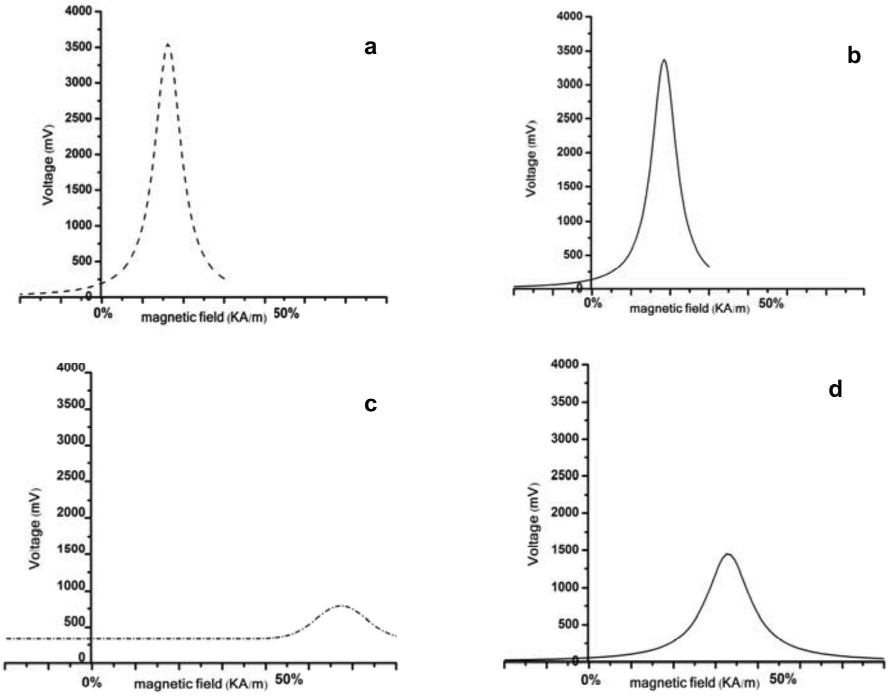


Figure 3. BN fingerprint (a)Annealed (b)Normalized (c)Quenched (d)Quench-temper(400 ˚C)

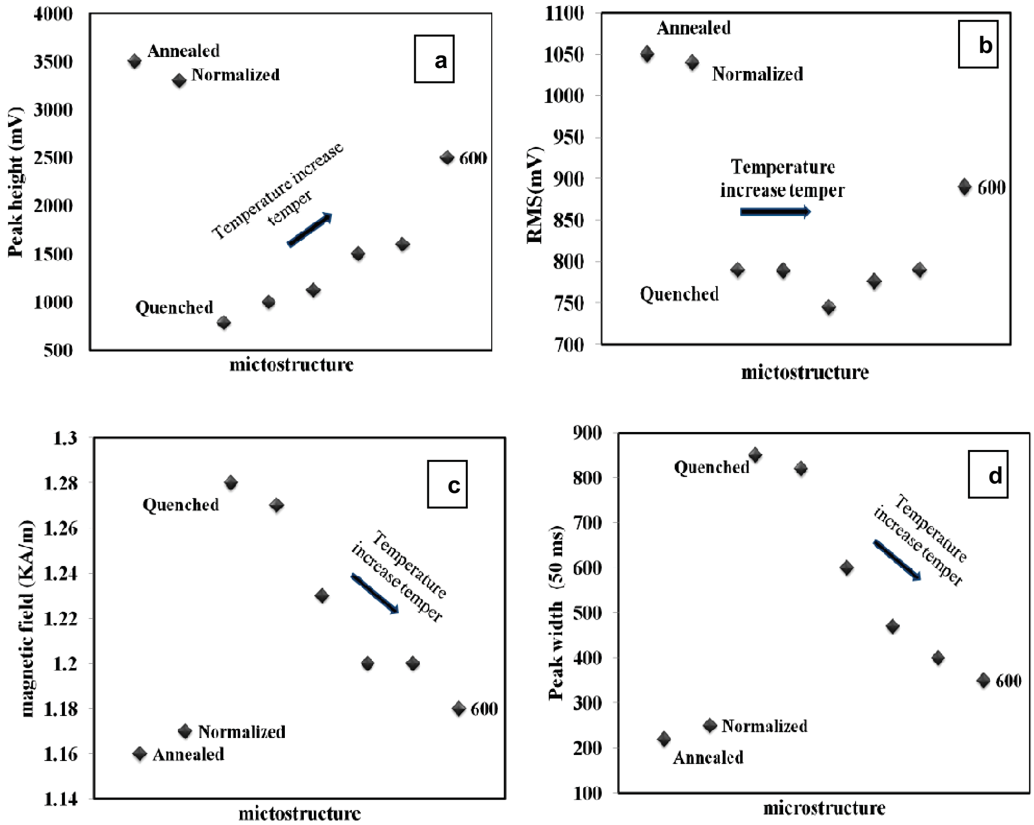


Figure 4. BN signals parameter (a) peak height(mV) (b)RMS(mV) (c)magnetic field (KA/m) (d)peak width(50ms)

Barkhausen noise signals in ferrite-pearlite and martensite structures

According to the results quenched structure has the lowest peak amplitude and these value increases in order of tempered martensite, fine pearlite-ferrite, and coarse pearlite-ferrite. Also, BN signal peak of ferrite-pearlite in a lower magnetic fields appear.

Mr. Vincent and et.al in similar research, considered Equation 1 for changes in the magnetic field around the specimen [10]:

$$\delta m = \beta(S.\delta l) \quad (1)$$

Where b is a coefficient related to the atomic magnetic moment and the type of domain wall, and S is the surface of the moving Bloch wall; $(S.\delta l)$ will hereafter be called source strength.

Domain wall motion (δl) in ferrite-pearlite structure, which has a lamination structure, is more than the compact needle shape martensite structure. In addition, surface of the moving Bloch wall, in ferrite-pearlite structure is more than martensite structure. Thus, magnetic field changes around the specimen, δm, in martensite structure is less than ferrite-pearlite structure. Increase δm in around a specimen, makes the BN signals appearing with higher intensity. In martensite specimen, BN signals peak has appeared in the higher applied magnetic field. Because, the mass motion of the walls happen in the higher applied magnetic field. This is due to the high dislocation density due to shear deformation on martensitic transformation, high distortion due to the confinement of atoms in the microstructure, formation twins in between the martensite needle. These factors act as barriers to the magnetic domain walls movement. Thus the higher magnetic field is required to moving walls than the ferrite-pearlite specimens.

Barkhausen noise signals in specimens with different temper temperature

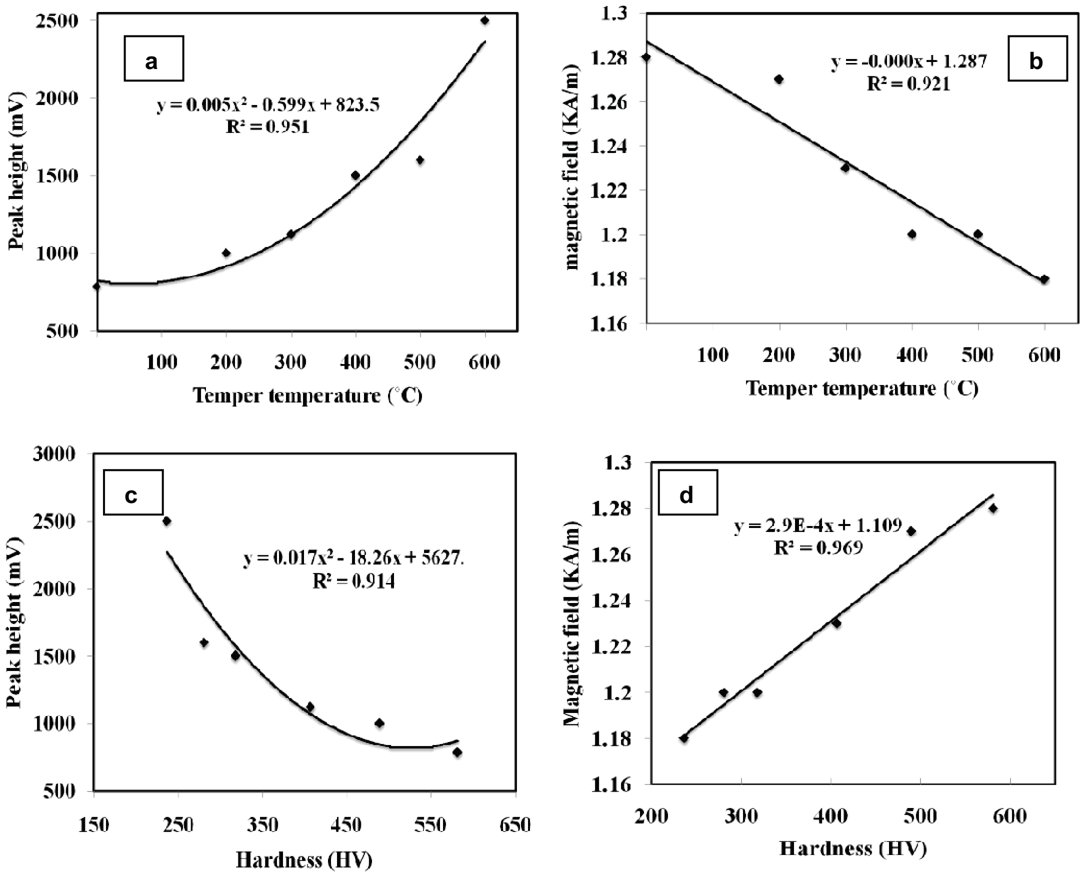
It can be seen that with increasing temper temperature, BN peak voltage rises**.** It is also observed that the maximum points in weaker magnetic fields appear. The changes in BN outputs are due to the changes in the microstructure during the tempering. Average size of the domains is very small in the qunched specimen due to small martensite needles. In addition, high dislocation density and residual stress induced martensitic transformation are barriers to domain wall motion. Temper temperature 200°C causes slight changes in microstructure. ε-carbides are formed, but the structure is still needles, which increases the BN voltage peak and reduce the applied magnetic field. In the range 200 to 400°C replaced cementite by ε-carbide. Compacts martensitic structure and dislocation density reduced. This makes moving easier the domain wall as well as increase range of motion them**.** At temperatures 600 to 500°C carbides start spheroidizing and residual stresses are almost completely relieved. In parallel to the morphological change in the microstructure, the magnetic structure becomes coarser, and the average size of domain walls increases. the BN signal amplitude increases remarkably, and the signal peak is situated at lower values of the magnetic field strength [11].

K. Davut in research done in 2006, BN results changes with temperature Temper, due to the change in dislocation density, size and shape of cementite and lattice strain (Residual stress) [12]. These results are consistent with previous studies that have been done in this area.

Prediction of hardness and temperature Temper using Barkhausen noise signal analysis

The main purpose of non-destructive testing, is evaluation of qualitative and quantitative metallurgical parameters using the results of these tests. Accurate estimates of parameters such as hardness, tensile strength, percentage of phases, decarburizing depth, temperature temper, etc, using the relationship between these parameters and the results is possible.

In the following, with using result of BN signals analysis and their relation with tempering temperature and hardness, accurate equations for estimating these two parameters are extracted. As can be seen in Figure 5, the best equation for each graph, that shows the relationship between the BN signal with hardness and temper temperature, are extracted. Regression analysis showed agreement experimental data with the equation is derived. Regression nearest to 1 for equations derived indicates high accuracy of these equations.



Fiure 5. Relation between (a) peak height, temper temperature (b)magnetic field, temper temperature (c) peak height, hardness (d)magnetic field, hardness

Conclusions

BN signals are affected by the magnetic properties of matter. Furthermore, the magnetic properties of the material depend on its microstructure, so this method is capable of separating materials with different microstructure. High Dislocation density, atomic network distortion and martensitic microstructure needles are barriers for movement of the domain, Therefore, in this microstructure, BN signals are less intense and occur in a stronger magnetic field. It also can be claimed that this method, can determine the tempering temperature as well as hardness of the unknown samples with low error. The high obtained correlation coefficients for relations between BN outputs and tempering temperatures indicate the potential of the proposed method.

References:

1. Cullity, B. D., Graham, C. D., Introduction to magnetic materials, Part9, Domain Wall Motion, IEEE Press 445 Hoes Lane Piscataway, Second Edition 2009, 301-305.

2. Kleber, X., Hug, A., Merlin, J., *Ferrite–Martensite Steels Characterization Using Magnetic Barkhausen Noise Measurement*. ISIJ International, Vol. 44 (2004), No. 6, pp. 1033–1039

3. Kleber, X., Hug-Amalric, A., *Evaluation of the Proportion of Phases and Mechanical Strength of Two-Phase Steels Using Barkhausen Noise Measurements: Application to Commercial Dual-Phase Steel. The Minerals, Metals & Materials Society and ASM International 2008*, Volume 39A, 1308-1318.

4. Silvério, F., Silva, J., "the use of magnetic barkhausen noise analisys for nondestructive determination of stresses in structural elements" International Nuclear Atlantic Conference - INAC 2007.

5. O. Stupakov, "Evaluation of Ductile Cast Iron Microstructure by Magnetic Hysteresis and Barkhausen Noise Methods".

6. Perez-Benitez, J.A., *Investigation of the magnetic Barkhausen noise using elementary signals parameters in 1000 commercial steel. Journal of Magnetism and Magnetic Materials* 263 (2003) 72–77.

7. Lungn, G., Saquet, O., "Determination of surface Hardened depth By Barkhausen noise", Universitatea Tehnica, Gh. Asschi, lasi Tomul XLVII(LI), Supliment, 2001.

8. Hakan GÜR, C., Davut, K., "Non-destructive Characterization of Pearlite Spheroidisation by Magnetic Barkhausen Noise Method" 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China.

9. Lindgren, M., *Effect of prestraining on Barkhausen noise vs. stress relation. NDT&E International*., 34 (2001) 337-344.

10. Saquet, O., Chicois, J., *Barkhausen noise from plain carbon steels: analysis of the influence of microstructure. Materials Science and Engineering*. A269 (1999) 73–82.

11. Hakan GÜR, C., "Comparison of Magnetic Barkhausen Noise and Sound Velocity Measurements for Characterisation of Steel Microstructures" ECNDT 2006 - Mo.2.2.4.

12. Davut, K., Hakan GÜR, C., "Characterisation of Quenched and Tempered Steels by Magnetic Barkhausen Noise Method" ECNDT 2006 - Poster 108.