Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume III, 190-193

Methodology and Experience in Applying a Non-Destructive Testing Method by Barkhausen Noise Analysis, for Example, in Ion-Treated Samples

Velichko Radoslavov Machev
Bulgaria University of Transport
„Technique and construction technologies in transport“ Faculty
Sofia, Bulgaria
vmatchev@vtu.bg

Nikolay Tonchev Tonchev
Bulgaria University of Transport
„Technique and construction technologies in transport“ Faculty
Sofia, Bulgaria
tontchev@vtu.bg

Abstract. **The present paper expresses the idea of the possibility of using a non-destructive method of research by means of Barkhausen Noise Analysis (BNA – Barkhausen Noise Analysis), replacing the conventional destructive methods for the examination of nitrided layers, making evaluations and comparisons with them. The paper refers to a specially created methodology, the implementation of which consistently follows the presentation of the paper. Comparing the non-destructive testing methodology with tribological, mechanical and metallographic research can outline which of the analyses can be substituted and what accuracy can be relied upon for the substitution. Heat-resistant steel BH21 was used as the object of research.**

The research is of practical value because the process has been established for this steel. The experience gained in this regard will help to expand and validate non-destructive testing methods.

Keywords: Ion nitriding, property identification, comparison between non-destructive and destructive testing methods.

I. INTRODUCTION

There is a wide range of fundamental and scientific-applied research in the field of methods and means of specialized methods for non-destructive testing, through which labour-intensive and time-consuming methods of destructive approaches can be replaced.

In the process of ion nitriding, because of the difference in the dimensions of the crystal structure of the different phase composition in the ion-treated layer, internal stresses arise. It has been shown that they can be characterized by analysing the characteristics of the magnetic noise [1, 2], caused by the dislocations in the microstructure in the examined ferromagnetic material. The information provided by these characteristics enables differentiated processing of the information used to evaluate the multi-parameter analysis of the nitriding mode and other types of processing of each individual input parameter [3, 4, 5]. This is possible thanks to the property of ferromagnetic bodies discovered by Barkhausen, whose magnetization under the action of an external magnetic field is accompanied by numerous jumps in magnetization. These jump-like changes are called Barkhausen jumps. These jumps are shown to be due to the jump-like displacement of the blast furnace walls. The domain wall is the transition boundary in a transition layer between two domains in which the magnetization spin direction gradually changes its orientation from a direction parallel to the magnetization vector of the first domain to a direction parallel to the magnetization vector of the second domain [6]. In the present research, the assessment is made by comparing traditional characteristics with those of magnetic noise caused by the Barkhausen effect, which according to expert opinion [7] is considered promising.

Apart from that, the authors have their own developed computational approach [8], which has proven its efficiency in the research of problems from engineering technologies. In addition to individual optimization calculations, it can also be used for identification of examined quality indicators, including for non-destructive technologies.

The brief review of the indicated research can determine the characteristic of the chosen topic, which is associated with the complexity and non-linearity of the various properties of the materials in the depth of processing of the considered surfaces. These new surface conditions are formed by a desired set of properties, which is determined by solving multicriteria problems [8, 9]. The latter guarantee certain benefits of the research, most often

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol3.8115

expressed in increased longevity (extended life) of contact products [10, 11]. All this relates to the production resource, characterization and applications in the field of hard coatings and wear-resistant surfaces.

II. MATERIALS AND METHODS

The present research aims to provide an idea and a methodology for applying a methodology proven in ion technology that works in practice, to be transferred to other related technologies. The chemical composition of the two steels is listed in Table 1.

TABLE 1. CHEMICAL COMPOSITION OF BH21 STEEL

Steels	C	Cr	Mo	V	W	Si	Mn	Ni	Cu	S
BH21	0,30	2,70	–	0,29	8,01	0,18	0,26	–	–	0,015

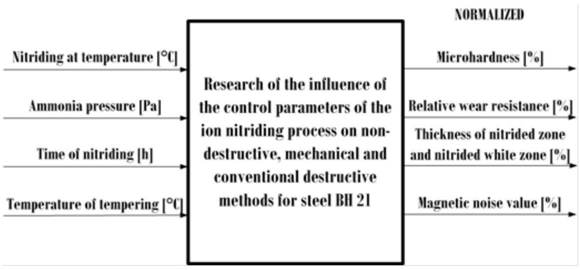

Fig.1. Input-output parameters in the statement of the problem

The influence of the technological parameters on the surface properties of BH21 steel depending on the conditions of ionic nitriding is examined. The complexity of the problem regarding identification in the technological process cited in Fig. 1 lies in the fact that there are more than two technological parameters, and the examined criteria have a different relationship to them. After establishing the relationship between technological parameters and examined criteria through the definition of the models, it is possible to apply a process of identification of surface properties depending on the processing mode. They can be evaluated by a non-destructive method. This process is established in [10, 11] by the limits of variation indicated in Table 2, by the derived models of the controlled quantities in Table 3 and by their extreme values indicated in Table 3.

TABLE 2. INTERVALS OF CHANGE OF TECHNOLOGICAL PARAMETERS

№	Parameter of the technological mode of ion nitriding and preliminary heat treatment	Extreme low	Average	Extreme upper
		Interval value of mode change		
		Code [–1]	Code [0]	Code [+1]
1	*Nitriding at temperature* t_{nit} *[°C] – (X_1)*	*510*	*530*	*550*
2	*Ammonia pressure* P_{NH3} *[Pa] – (X_2)*	*150*	*300*	*450*
3	*Time of nitriding* *t [h] – (X_3)*	*4*	*7*	*10*
4	*Temperature of tempering* t_{tem} *[°C] – (X_4)*	*600*	*650*	*700*

The derivation of the models in [10, 11] was done with the methodology presented in [8], and the optimization of the models was performed with [9].

Using [9] there were produced the models shown in Table 3.

TABLE 3. COEFFICIENTS OF THE MODELS FOR THE INFLUENCE OF NITRIDING PARAMETERS ON THE VALUE OF THE INVESTIGATED CRITERIA

Coefficients	**BH 21, microhardness**	**BH21, linked zone**	**BH21, wear resistance**	**BH21, total thickness of the nitrided zone**
b_0	1102.94	3.66667	0.511111	257.60
$b_1{*}X_1$	–7.93750	2.12500	–0.085625	33.810
$b_2{*}X_2$	–3.56250	1.12500	–0.018125	–0.330
$b_3{*}X_3$	3.06250	–	–0.068125	42.640
$b_4{*}X_4$	–55.6875	0.8750	0.030625	–7.910
$b_5{*}X_1^2$	–	–	–	0.250
$b_6{*}X_1X_2$	–3.93750	0.8750	0.0118750	0.6250
$b_7{*}X_1X_3$	3.68750	0.250	0.00437500	–6.880
$b_8{*}X_1X_4$	25.4375	–0.3750	0.010625	–0.630
$b_9{*}X_2^2$	–	–	–	–19.750
$b_{10}{*}X_2X_3$	–22.4375	–0.250	–0.060625	–1.870
$b_{11}{*}X_2X_4$	11.0625	–0.1250	0.0081250	–5.630
$b_{12}{*}X_3^2$	–	–	–	–19.750
$b_{13}{*}X_3X_4$	–12.3125	–0.250	–0.0443750	–5.630
$b_{15}{*}X_{42}$	–	–	–	–24.750

Through the derived models when applying [10], the extremes of the steel can be determined for each of the parameters. This determined the modes in Table 4.

TABLE 4. EXTREME VALUES OF THE EXAMINED PARAMETERS

Object	**Microhardness**		**Wear resistance**		**Linked zone thickness**		**Nitrided zone total thickness**	
BH21	Min: 1005.82	$X_1 = 510$	Min: 0.28	$X_1 = 550$	Min: 0.33	$X_1 = 510$	Min: 89.235	$X_1 = 510$
		$X_2 = 450$		$X_2 = 450$		$X_2 = 150$		$X_2 = 450$
		$X_3 = 10$		$X_3 = 10$		$X_3 = 4$		$X_3 = 4$
		$X_4 = 700$		$X_4 = 600$		$X_4 = 600$		$X_4 = 700$
	Max: 1236.82	$X_1 = 510$	Max: 0.77	$X_1 = 510$	Max: 8.417	$X_1 = 550$	Max: 341.18	$X_1 = 550$
		$X_2 = 150$		$X_2 = 450$		$X_2 = 450$		$X_2 = 170$
		$X_3 = 10$		$X_3 = 4$		$X_3 = 4$		$X_3 = 10$
		$X_4 = 600$		$X_4 = 600$		$X_4 = 700$		$X_4 = 650$

This review would be more targeted if a methodology could be analytically or numerically defined to fix the influence of different modes on surfaces that are determined as destructive and non-destructive.

III. RESULTS AND DISCUSSION

Through non-destructive and traditional destructive testing methods, the quality of the products is ensured. Non-destructive testing methods have one significant advantage over all other control methods, which consists in checking each specific product without disturbing its integrity. For this reason, the methodology – object of this research – was created and verified.

The specific research tests the methodology by comparing the value of the measured noise with the results of the models indicated in Table 3 and the extreme values of the examined quantities indicated in Table 4. The algorithm of the methodology is shown in Fig.2.

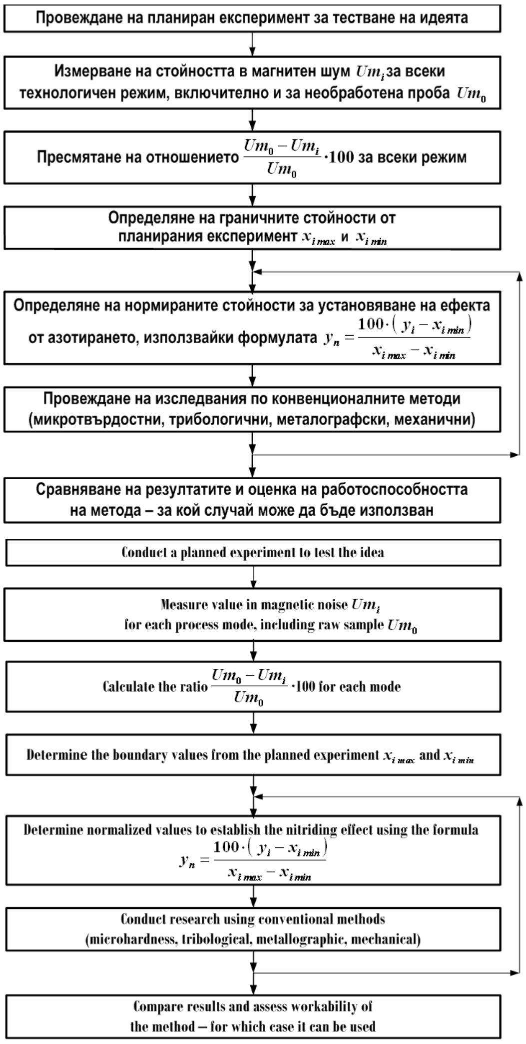

Fig.2. Methodology algorithm

The most essential part of the presented methodology is the calculation of all the examined quantities and their normalization so that the comparison itself can be realized. This is how the credibility of the results is achieved and they can be justified for the purpose of their future use.

TABLE 5. RESULTS OF THE COMPARISON OF THE NON-DESTRUCTIVE CHARACTERISTIC WITH THE DESTRUCTIVE ONES

Mode No.	*Umn* [%]	Wear resis-tance [%]	Micro-hardness [%]	Thick-ness nitrided layer [%]	Thick-ness white zone [%]
t_{nit}=510 [°C], P_{NH3} = 150 [Pa], τ = 4 [h], t_{tem} = 700[°C]	0	15,306	35,93	9,57	31,99
t $_{nit}$=530 [°C], P_{NH3} = 300 [Pa], T= 2.76 [h], t_{tem} = 650[°C]	32,76	36,93	40,216	37,31	41,26
t_{nit} =530 [°C], P_{NH3} = 300 [Pa], T=7 h, τ= 7 [h], t_{tem} = 650[°C]	52,84	52,86	42,42	66,86	41,26
t_{nit} =530 [°C], P_{NH3} = 88 [Pa], τ= 7 [h], t_{tem} = 650[°C]	61,809	47,55	44,58	51,35	21,59
Absolute deviation from the normalized voltage of the measured noise		8.44	17.76	9.65	23.07

To experimentally verify the presented methodology, a real experiment was performed in which the results were compared between the characteristics of the non-destructive testing by means of Barkhausen noise analysis and those of the conventional methods of analysis. Because of the inspection, the following results were obtained.

A graphical interpretation of the results of this comparison is presented in Fig.3.

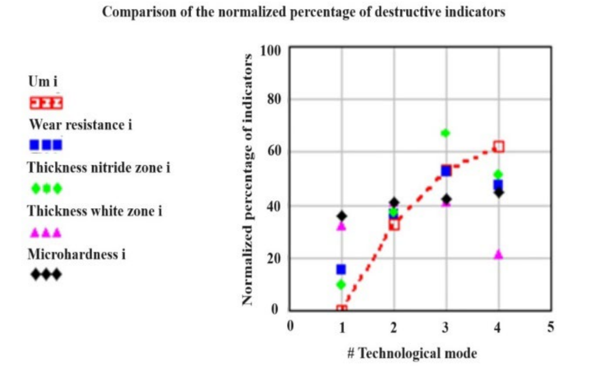

Fig.3. Graphical representation of the comparison results

From this check, the influence of the various parameters of the nitriding mode on the Barkhausen noise characteristic for steel BH21 was determined. Based on this theoretical-experimental research, the following main conclusions can be drawn, which derive directly from Table 5 and Fig. 3.

1. The maximal recoil temperature is associated with the minimally normalized Barkhausen noise characteristic for steel BH21.

2. For BH21 steel, the nitriding process time has less effect on the Barkhausen noise value for BH21 steel than the gas pressure.

3. For each of the examined quality indicators, the absolute deviation from the normalized Barkhausen noise characteristic was determined, and this result ranked the mechanical and destructive methods of analysis. The analysis of this research proves that the non-destructive Barkhausen noise settling method can be successfully applied to the relative wear resistance and the total thickness of the nitride zone for which the deviation is less than 10%.

4. For the final proof of the workability of the methodology, it is necessary to confirm these statements with nitriding under the same conditions on another steel, although the different alloy composition may lead to certain smaller or larger deviations.

IV. CONCLUSION

In conclusion, it is necessary to note that through the research done, the possibility of using the non-destructive research method through Barkhausen Noise Analysis (BNA) replacing the conventional destructive methods for researching nitrided layers, making evaluations and comparisons has been clarified between them. The comparison of the proposed non-destructive methodology with tribological, mechanical and metallographic research reported which of the analyzes can be replaced and what accuracy can be relied on in this replacement. The research refers to heat-resistant steel BH21. The microstructure of the nitrided layer plays an indirect role through the depth distribution of the phases. Through the study, the relationship between phase composition, technological mode and percentage of normalized destructive tests was found. A non-destructive test has been developed and tested, which can be an alternative to existing destructive methods. We believe that the research also has practical value because the process has been established for this steel. Such experience will help to expand and validate non-destructive control methods.

REFERENCES

[1] Makowska, K., Piotrowski, L., Kowalewski, Z.L.: Prediction of the mechanical properties of P91 steel by means of magneto-acoustic emission and acoustic birefringence. J. Nondestruct. Eval. 36, 43 (2017) https://doi.org/10.1016/j.jnucmat. 2015. 07. 038. ;

[2] Stupakov, O. Local non-contact evaluation of the ac magnetic hysteresis parameters of electrical steels by the Barkhausen noise technique. J. Nondestruct. Eval. 32, 405–412 (2013) https://doi.org/10.1016/B978-0-08-102800-1.00009-5 ;

[3] Samimi, A.A., Krause, T.W., Clapham, L.: Multi-parameter evaluation of magnetic Barkhausen noise in carbon steel. J. Nondestruct. Eval. 35, 40 (2016) https://doi.org/10.1007/ s10921-016-0358-4 ;

[4] Piotrowski, L., Chmielewski, M., Kowalewski, Z.L.: The dominant influence of plastic deformation induced residual stress on the Barkhausen effect signal in martensitic steels. J. Nondestruct. Eval. 36, 10 (2017) https://doi.org/10.1007/ s10921-016-0389-x

[5] Moorthy, V., Shaw, B.A., Mountford, P., Hopkins, P.: Magnetic Barkhausen emission technique for evaluation of residual stress alteration by grinding in case-carburised En36 steel. Acta Mater. 53, 4997–5006 (2005) https://doi.org/10. 1016/j.actamat.2005.06.029.

[6] Santa-aho, S., Vippola, M., Sorsa, A., Latokartano, J., Lindgren, M., Leiviskä, K., Lepistö, T.: Development of Barkhausen noise calibration blocks for reliable grinding burn detection. J. Mater. Process. Technol. 212, 408–416 (2012) https://api.semanticscholar.org/CorpusID:137217703

[7] Vashista, M., Moorthy, V.: Influence of applied magnetic field strength and frequency response of pick-up coil on the magnetic Barkhausen noise profile. J. Magn. Magn. Mater. 345, 208–214 (2013) https://doi.org/10.1016/j.jmmm.2013. 06.038.

[8] Tontchev, N., „Materials science, Effective solutions, and technological variants“, Lambert, Academic Publishing, 2014, 142 p., https://www.semanticscholar. org/paper/Materials-Science%2C-Effective-Solutions-and-Variants Nikolay/e5904f3bc8c5ddd127daf5e6f798d1d931cae7a3

[9] Tontchev, N., Gaydarov, V., N. Hristov, N., Analyzes and applications through thecomputational approach DEFMOT, Sofia, 2022, 167 p. (in Bulgarian),

[10] Zumbilev, A.P., Zumbilev, I.A., Ionic nitriding and carbonitriding of steels, 2020, pp. 325, ISBN: 978-619-236-187-7 (in Bulgarian), https://e-university.tu-sofia.bg/e-publ/search-det.php?id=6805 .

[11] Zumbilev, I., About wear resistance of nitrided and carbonitrided layers, Journ. "Annals of the Faculty of Engineering Hunedoara", Tome XIII, Fascicle 1, Romania, 2015, pp. 53-56.

[16] Vuchkov, I., Boyadjieva, L., Quality Improvement with Design of Experiments. A Response Surface Approach, 2001, https://link.springer.com/book/10.1007/978-94-009-0009-7