YOUNG FORUM
Mechanics Transport Communications
Academic journal http://www.mtc-aj.com article № 2356

ISSN 2367-6558 (print)
ISSN 2367-6612 (online)
volume 12 issue 1, 2023

IDENTIFICATION OF SURFACE PROPERTIES OF STEEL BH11 DEPENDING ON THE CONDITIONS OF IONIC NITRIDING

Velichko Machev, Viktor Georgiev, Nikolay Tonchev, Iliya Zyumbilev
vmatchev@vtu.bg, viktor_georgiev@vtu.bg, tontchev@vtu.bg

Todor Kableshkov University of Transport
1574 Sofia, 158 Geo Milev Str.
THE REPUBLIC OF BULGARIA

Key words: *ion nitriding, heat resistant tool steels, modeling, property identification, optimization, DEFMOT.*

Abstract: *In this communication, the influence of the technological parameters on the surface properties of BH11 steel depending on the conditions of ionic nitriding is examined. The complexity of the problem regarding the identification of the cited technological process 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. For this process, the DEFMOT system was used to support technological decision-making. With the help of this system, images were built, and analysis was made for the microhardness, the relative wear resistance, the thickness of the nitrided zone and the phase composition of BH11 steel depending on the conditions of ion nitriding.*

INTRODUCTION

Efficient technological modes bring benefits to the production process. In order to discover these modes, however, it is necessary that the process under consideration be fully defined in terms of the set objectives. This is the only way to reach a rational solution with a certain economic effect. This seemingly elementary formulation of the problem inevitably becomes more complicated when examining real problems, characterized by a greater number of governing factors that simultaneously affect the various investigated quality indicators. Modern means of automating engineering work create good conditions for intelligently solving such problems. One such solution [1] has proven its workability in the research of engineering technology problems. In addition to individual optimization calculations, it can also be used for the identification of examined quality indicators.

The main parameters affecting the operational surface properties of structural and tool steels are determined by the chemical-thermal treatment mode and the composition of the material being treated. The surface integrity during processing is summarized in [2], which describes the basic achievements in the research of contact strength after chemical heat treatment. Tribological issues, and in particular those related to wear resistance, need to be identified before the process of designing treatment modes when it comes to thermal or chemical treatment. In this case, the tribological concept will be most useful in practice.

Similar research is described in the monograph [3], where the relationship between the goal parameters and the technological factors of the modes for processing are defined.

The brief overview of this research can determine the characteristics of the chosen topic, which is associated with complexity and nonlinearity, in properties of materials in depth of the examined surfaces. These new surface conditions are formed by a desired set of properties, which is determined by solving multicriteria problems [4, 5]. The latter guarantee certain benefits of the research, most often expressed in increased longevity (extended life) of contact products [6, 7]. All this is related to the resource for production, characterization and applications in the field of hard coatings and wear-resistant surfaces. This review would be more targeted if a methodology could be analytically or numerically created to establish the influence of different modes equally affecting an entire class of steels. In this way, the particular influence of one or another alloying element as a concentration and in combination with other elements will be ignored.

The purpose of the present research is to apply the DEFMOT technological decision support system for identification of surface properties of BH11 steel depending on the conditions of ion nitriding.

STATEMENT OF THE PROBLEM

The stages and the sequence of work in the research are subject to the methodology described in [1]. Since this methodology was developed for the four parameters, these guarantees, on the one hand, the adequacy of the subsequently obtained results, and on the other hand, an intelligent presentation of the very solution. After the selection of an object for research – heat-resistant steel BH11 with a defined composition, shown in Table 1 and initial properties in Table 2, a plan is defined for processing the research samples with bounds' variation parameters according to Table 3.

Table 1. Chemical composition of steel from the class, [%]

Steel	C	Cr	Mo	Si	Mn	W	V	Ni	Cu	S
BH11	**0,38**	**4,50**	**1,20**	**0,91**	**0,22**	**–**	**0,47**	**0,14**	**0,11**	**0,006**

Table 2. Characteristics of the steels

Steel	Yield strength *Rm* [MPa]	Tensile strength *Re* [MPa]	Impact strength *KCU* [kJ/m^2]
BH11	**1480**	**1750**	**570**

After running the experiment, using a standard statistical procedure described in [8], adequate models are derived. After checking the adequacy of the models, the specific results of the identification are determined.

$$HV_{0.1} = 11914.4+254.13X_1-143.65X_2+134.44X_3 - 274{,}03X_4 - 51.50X_1^2+248.75X_1X_2 - 88.75X_1X_3 - 136.25X_1X_4 - 624.00X_2^2 - 301.25X_2X_3+76.25X_2X_4+194.00X_3^2 - 36.25X_3X_4 - 144.00X_4^2 \quad (1)$$

$$Kv = 0.4020 - 0.0828X1 + 0.0033X2 - 0.0523X3 - 0.0008X4 + 0.0037X12 + 0.0106X1X2 + 0.0244X1X3 - 0.0006X1X4 + 0.0087X22 - 0.0469X2X3 + 0.0031X2X4 + 0.0237X32 + 0.0093X3X4 + 0.0512X42 \quad (2)$$

Table 3 Variation range of the input parameters

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

$$\delta_{св.з.} = 8.0 + 2.47X_1 + 0.92X_2 + 1.47X_3 - 0.8X_4 - 1.13X_1^2 + 0.44X_1X_2 - 0.06X_1X_4 - 0.88X_2^2 + 0.437X_2X_3 - 0.19X_2X_4 - 0.13X_3^2 + 0.31X_3X_4 - 0.88X_4^2 \quad (3)$$

$$\delta_{общ.} = Y_2 = 224{,}00 + 35{,}99X_1 + 6{,}67X_2 + 24{,}74X_3 - 5{,}04X_4 - 28{,}75X_{12} + 0{,}625X_1X_2 + 4{,}38X_1X_3 - 15{,}63X_1X_4 - 33{,}75X_2^2 + 6{,}88X_2X_3 - 0{,}625X_2X_4 + 6{,}25X_3^2 + 5{,}63X_3X_4 - 21{,}25X_4^2 \quad (4)$$

Since the parameters from Table 3 are four and the range of their change is too wide, it is necessary to create a graphic-calculation way to easily determine the trends in the change of properties, with the starting point being a set percentage of the minimal or maximal value. After defining the modes which determine one or other properties, we will proceed to the interpretation of these properties in relation to the nitride zone and the phase composition. For this reason, based on data from metallographic research for 25 technological modes performed in [3], an equation for the phase composition was additionally derived. These modes are coded 1, 2, and 3 depending on whether the obtained result after layer processing is with α, γ, and $\gamma + \varepsilon$. This equation has the form:

$$F_{(\alpha,\gamma,\gamma+\varepsilon)} = 2.01825 + 0.05025X_1 + 0.17525X_2 + 0.37079X_3 - 0.0270649X_1^2 - 0.0405855X_1X_2 + 0.125X_1X_3 + 0.5X_1X_4 + 0.0613369X_2^2 - 0.125X_2X_4 + 0.0452575X_3^2 + 0.125X_3X_4 \quad (5)$$

After defining the models, it is possible to apply a surface property identification process depending on the processing mode. For this process, the DEFMOT system [9] will be used to support technological decision making.

RESEARCH RESULTS

The scheme (Fig. 1) through which the identification of the surface properties of BH11 steel is зеиодипеа depending on the conditions of ion nitriding uses the following blocks for the calculations.

Using Fig. 1, in the images discussed below, notations are used according to Table 3. In the large global quadrant, in all listed images, the nitriding temperature is changed horizontally in nine evenly spaced steps from 510 to 550 [°C]. Vertically in the same quadrant, again in 9 steps from top to bottom, the gas pressure changes from 150 to 450 (at the bottom) [Pa].

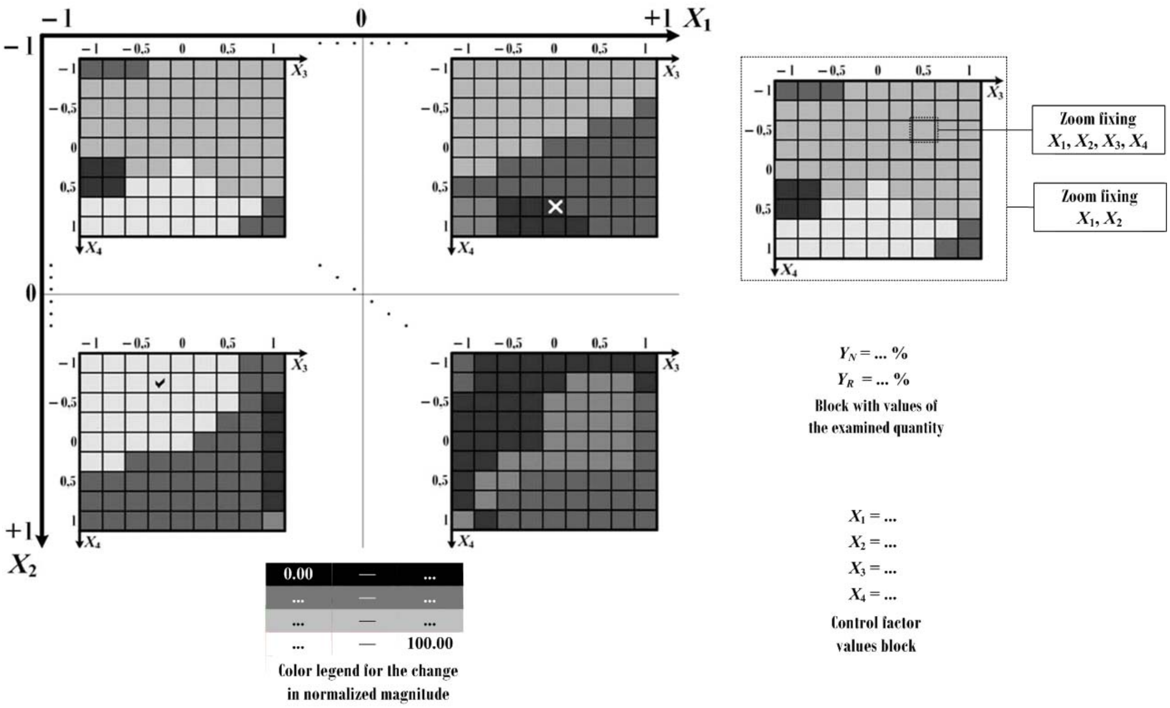

Fig. 1. Used template for surface identification properties depending on the processing mode

The global representation of these two parameters in the definition area is fixed by a moving zoom. The zoom contains all nine states of change also of the third and fourth parameters. Changing its position, the zoomed image is projected to the right in a smaller quadrant. To determine a specific state and identify the current value of the examined quantity, it is necessary to move the zoom in the small right-hand quadrant from the control parameters. In this quadrant, also in nine equally distributed steps, the nitriding time [h] changes horizontally, and the retort temperature [°C] vertically. Values calculated by the model are written below the quadrant. For easy analysis, a percentage editor is available through which thresholds can be set for coloring the response surface. The coloring can be done with an arbitrarily chosen step which controls the corresponding color image of the large and small quadrants.

The research analysis can first be performed with both the colors and the coordinates of the minimal and maximal values in the quadrant. These values in the quadrant are shaded gray, but the maximal value is surrounded (or bordered by) the violet values, and the minimum is also shaded gray on a blue border area.

With the scheme thus described, below are shown the obtained images from identification of hardness, relative wear resistance, thickness of the nitrided zone and phase composition.

Similar to Fig. 1, in Fig. 2 and Fig. 3, the arrangement of maximal values of the thickness of the nitrided zone and the thickness of the bonded zone, respectively, is fixed. It is noteworthy that the maximal values of these two criteria have close parameters, such as the maximal temperature and the nitriding time. Almost identical is the retort temperature, around 650 [ºC]. As the only insignificant differences in the maximal values of the two thicknesses, the gas pressure can be considered. A larger bonded area is recorded at a higher pressure – 450 [Pa].

When considering microhardness (Fig. 4) and wear (Fig. 5) together, it should be noted that at their maximal values these are reciprocal criteria only as quality. Minimal wear is associated with the maximal wear resistance corresponding to higher hardness values. By identification, this is the lower right quadrant of the global matrix. The ion nitriding process, especially for BH11 steel, introduces certain features and one of the aims of the research is to determine these features. Analyzing Fig. 3 and Fig. 5 the minimal wear can be established and that it is at modes determined with the greatest depth of the bonded zone. The identification determined a suitable mode for this purpose – maximal temperature – 550 [°C] and nitriding time – 10 [h], retort temperature 650 [°C] and gas pressure 450 [Pa]. This is also confirmed by Fig. 6, where the phase composition of this mode is set by $\gamma + \varepsilon$.

CONCLUSIONS

Analysis of the mutual influence of multiple control parameters defined as identification becomes difficult, and for this reason the DEFMOT system was used. Its advantages are:

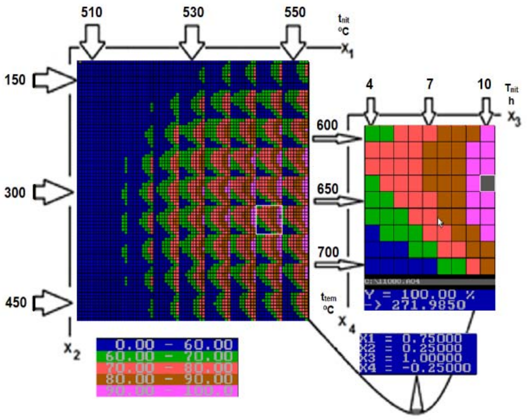

Fig. 2. Identification of the thickness of the nitrided zone of steel BH11 depending on the conditions of ion nitriding

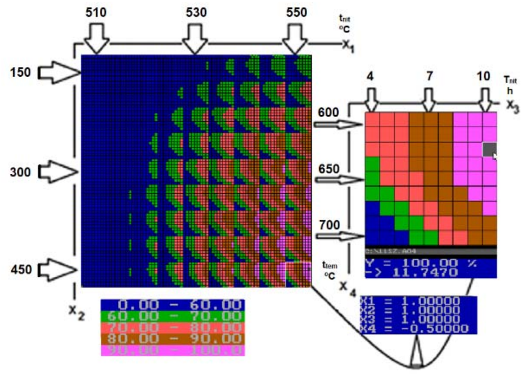

Fig. 3. Identification of the thickness of the bonded zone of steel BH11 depending on the conditions of ion nitriding

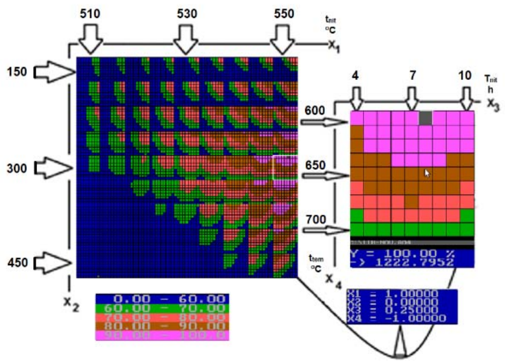

Fig. 4. Identification of the hardness of the nitrided layer of steel BH11 depending on the conditions of ion nitriding

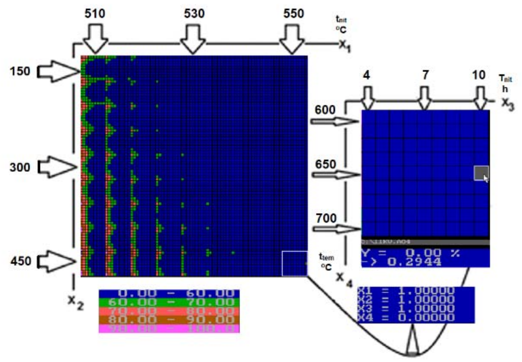

Fig. 5. Identification of the relative wear resistance of the nitrided layer of steel BH11 depending on the conditions of ion nitriding

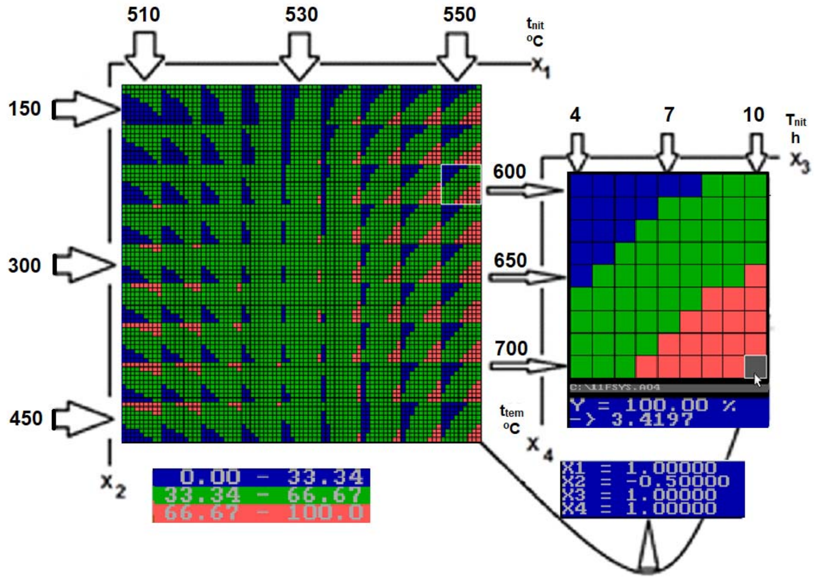

Fig. 6. Identification of the phase composition of the nitrided layer of BH11 steel depending on the conditions of ion nitriding

1. The exact complex interaction between parameters such as value and normalized percentage of the maximum. The interaction is visualized and can be justified iteratively by refining color intervals.
2. The identification is done through a friendly oriented system, initially working with colors and upon reaching the desired solution for a maximum or minimum, the meanings of the governing parameters and the examined quantities are specified.
3. The system has been successfully applied in comparing two or more different properties subjected to the same technology to demonstrate effectiveness.
4. Identification is applied to analyze multiparameter polynomials. The specialized way of representation makes it possible to trace each value from the model and its corresponding address. Based on this, a common cross-section between all examined criteria was determined.

Acknowledgments: The idea of the present article was inspired by a funding proposal for the project "To LEarn to AnaLyze and Optimize in 5D Space for Certain Benefits" - LEAL 5D (true, loyal-5D)" from La Fondation Dassault Systèmes. In this regard, the authors thank opportunity.

REFERENCES

[1] Tontchev, N., Materials science, Effective solutions, and technological variants, Lambert, Academic Publishing, 2014, 142 p.
[2] Paulo, D.J., Surface Integrity in Machining Springer, 2010, 222 p.
[3] Zumbilev, A.P., Zumbilev, I.A., Ionic nitriding and carbonitriding of steels, 2020, 325 p., ISBN: 978-619-236-187-7 (in Bulgarian)
[4] Abdelkhalik, O., Engineering Systems Optimization, Boca Raton:CRC Press, 2021, 230 p.
[5] Statnikov, R.B., Matusov J.B., Multicriteria Optimization and Engineering, Springer, 1995, 250 p.

[6] Zumbllev, I., About the influence of ion carbonitriding on the chemical composition of the carbonitride zone, Journal of Food and Packaging Science, Technique and Technologies, No. 8, National Academy of Packaging, Bulgaria, 2016, pp.10-13.
[7] 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.
[8] Vuchkov, I., Boyadjieva, L., Quality Improvement with Design of Experiments. A Response Surface Approach, 2001.
[9] Тончев, Н, Гайдаров, В., Н. Христов, Н., Анализи, и приложения чрез изчислителния подход DEFMOT, София, 2022, 167 p. (in Bulgarian)