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MATHEMATICAL AND EXPERIMENTAL MODELLING OF THE ELECTRON BEAM SURFACE HARDENING

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Abstract: *The work presents the results of the mathematical and experimental modelling of the electron beam surface hardening applied to steels: OLC 45 and 42 MoCr11 in order to establish the "layer hardness" process function. Based on the methodology proposed by the authors, process functions are defined for the electron beam treated layer hardness, as determined in five experimental points, for the two above-mentioned materials. Once defined, the process functions allow determining the effects of the process parameters on electron beam hardening.*
Key words: *Mathematical and experimental modelling, hardening, electron beam*

1. INTRODUCTION

The electron beam hardening is a high performance procedure of surface thermal treatment, very little industrially used in work-piece surface hardening due to insufficient knowledge of the adequate working conditions. The optimization of this process faces today many difficulties because of the lack of mathematical models, which should allow studying the effects of the main electrical and technological parameters on the process functions, termed as technological characteristics.

Today specialist publications do not provide process functions definitions to allow determining hardness in several points of the electron beam hardened strip. With this purpose in view, this work tries to present a part of the researches developed by the authors related to theoretical and experimental modelling of electron beam surface hardening, which refers to the determination of the main process function, called "layer hardness" *HV*, by making use of the methodology elaborated by the authors (Neagu 1999, Vişan et al., 1999). To identify the space distribution of the layer hardness after hardening, as well as the width and depth of hardened strip is most important for determining the degree of strip superposition, to obtain a uniformly hardened layer in the case of electron beam hardening of parts (Neagu, 1999).

Considering these functions this research work will continue by determining the effects of the main electrical-technological parameters on the layer hardness.

2. ESTABLISHING OF VARIABLES

Independent variables. Based on preliminary research, as independent variables x_k, $k = 1,2,\dots, 5$, the following electrical-technological parameters of the process were assumed: working distance - L_l, electron beam current intensity - I_{FE}, accelerating voltage - U_a , running speed - V_m and cross deflection angle β. Taking into account the difficulties encountered by the authors to characterize the hardened material by numerically expressed properties, the assessment of its influence on the process function - "layer hardness" *HV* - was made by establishing this function separately for two materials, OLC45 as a reference material and 42MoCr11C. In modelling the hardening process, the order variables, such as: focusing current intensity - I_F , number of passing - N_t , gas pressure within the cannon - P_t, and pressure within the working chamber - P_l , were kept constant.

Dependent variables. Based on the methodology proposed by the authors (Neagu 1999, Vişan et al., 1999), to model the electron beam surface hardening process, the following dependent variables were assumed as process functions: layer hardness - *HV*, hardened layer thickness - H_s and hardened strip width - L_{HV}. In this report there are presented only the research regarding the determination of the process function "layer hardness" *HV*.

3. ESTABLISHING OF PROCESS FUNCTION EXPRESSION

The general form of process functions. For the accurate determination of layer hardness, two types of process functions are examined in general form, which frequently apply in specialist publications (Gheorghe et al., 1985) with very good results in the case of similar technological processes (Visan, 1998, Ioan et al., 1998) that is the polytropic and polynomial functions, as indicated below:

$$Y = A_0 \cdot X_1^{A_1} \cdot X_2^{A_2} \cdot X_3^{A_3} \cdot X_4^{A_4} \cdot \ldots X_k^{A_k} \quad (1)$$

$$Y = a_0 + \sum_{k=1}^{5} a_k \cdot X_k + \sum_{j=1}^{4} \sum_{k=j+1}^{5} a_{jk} \cdot X_j \cdot X_k \quad (2)$$

where *Y* is the dependent variable, X_k independent variable and $A_0, A_1,\dots, A_k$ şi $a_0, a_1,\dots, a_{jk}$ are the regression coefficients of the two types of process functions to be determined by mathematical and experimental modelling.

The specific form of process functions. To define the "layer hardness" process function, we have determined the specific form of the two process functions given by relations (1) and (2) for the concrete case of electron beam hardening process:

$$HV = A_0 L_l^{A_1} \cdot I_{FE_k}^{A_2} \cdot U_{a_k}^{A_3} \cdot V_{m_k}^{A_4} \cdot \beta_k^{A_5} \quad (3)$$

$$HV = A_O + a_1L_l + a_2I_{FE} + a_3U_a + a_4V_m + a_5\beta + a_{12}L_lI_{FE} + a_{13}L_lU_a + a_{14}L_lV_m + a_{15}L_l\beta + a_{23}I_{FE}U_a + a_{24}I_{FE}V_m + a_{25}I_{FE}\beta + a_{34}U_aV_m + a_{35}U_a\beta + a_{45}V_m\beta \quad (4)$$

where the values have the above mentioned significance.

4. RESEARCH METHODS AND EQUIPMENT

Research methods. To determine the process function - "layer hardness"-HV, we prepared and achieved an experimental programme comprising 20 experiences.

Table 1 presents the natural and codified levels of the five independent variables.

Independent variable, X_K	Levels	Minimum		Medium		Maximum	
		X_k^1	-1	X_k^2	0	X_k^3	+1
$X_{K,}$ K = 1,2,..., 5	$X_1 = L_l$ [mm]	80	-1	85	0	90,3	+1
	$X_2 = I_{FE}$ [mA]	8	-1	9	0	10,1	+1
	$X_3 = U_a$ [kV]	44,5	-1	45	0	45,5	+1
	$X_4=V_m$[m/min]	1,5	-1	1,8	0	2,16	+1
	$X_5 =\beta$ [deg.]	80	-1	90	0	101,2	+1

Tab. 1. Natural and codified levels of the independent variables of the process

The natural levels X_k^u, of the variables are in geometrical progression, whereas the codified ones are in arithmetical progression. The structure of the experimental programme, determined by 16 different experiences and 4 identical experiences, levels, discrete values and experiences content were settled so that the programme would be compatible and orthogonal.

The programme was rejoined for each of the two searched materials. To process mathematically the experimental data it was used the *REGS* programme, which permitted to determine the coefficients of regression, indicators of regression, statistical errors as well as afferent confidence intervals.

The hardness obtained as a result of the electron beam hardening within the preliminary research proved to be a variable that depends also on the *x* and *z* coordinates of the points in the hardened zone. In order to determine the process function *HV*, hardness was measured in several characteristic points, that is in the points a_0, b and c located on the beam axis and, respectively, in symmetrical points a_{s1}, a_{d1}, a_{s2}, a_{d2} and b_s, b_d, c_s and c_d, represented in figure 1.

Research means. The experiments were carried out on 16kW electron beam installation produced by IFIN Institute, Măgurele, Romania. The materials used for research were the steels OLC 45 and 42 MoCr 11. It was applied the hardening method for flat surfaces by long and continue impulses, named "hardening in successively spaced strips".

To position, orient and fix the samples, a special device was used that allowed to adjust the electron beam parallelism as against the sample edge on the OY axes direction (figure 1). The sample pieces were shaped as a parallelepiped. The determination of the experimental data, needed to determine the process function *HV*, was made by means of *NEOPHOT 32* microscope, according to STAS 4203-74 and STAS 7057-78.

5. PROCESS FUNCTIONS

On the basis of the experimental data, the polytropic and polynomial process functions - "Layer hardness" HV - were established for the two examined materials in all the points characteristic to the hardened zone made evident in figure 1. Due to their satisfactory precision and easily utilization, in what follows only the polytropic functions are retained for examination.

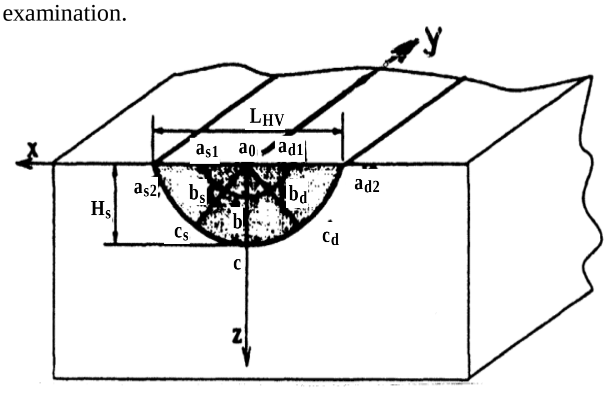

Fig. 1. The measurement points

Since the hardness values are identical in the symmetrical points as against OZ axis, we will consider only the process functions for points a_O, b and c and a_{s2} and c_s, defined also as indices for the two research materials, OLC 45 - index "OLC", and 42 MoCr 11- index "MoCr", as follows:

"Layer hardness HV" process functions for steel OLC 45:

$$HV_{a_O OLC} = 11{,}881 \cdot L_l^{0,351} \cdot I_{FE}^{0,322} \cdot U_a^{0,495} \cdot V_m^{0,343} \cdot \beta^{0,028} \quad (3)$$

$$HV_{bOLC} = 5{,}481 \cdot 10^{-4} \cdot L_l^{-0,084} \cdot I_{FE}^{0,191} \cdot U_a^{3,505} \cdot V_m^{0,357} \cdot \beta^{0,196} \quad (4)$$

$$HV_{cOLC} = 6{,}596 \cdot 10^{-6} \cdot L_l^{0,107} \cdot I_{FE}^{0,206} \cdot U_a^{4,412} \cdot V_m^{0,322} \cdot \beta^{0,203} \quad (5)$$

$$HV_{a_{s_2} OLC} = 0{,}391 \cdot L_l^{0,185} \cdot I_{FE}^{0,270} \cdot U_a^{1,553} \cdot V_m^{0,381} \cdot \beta^{0,046} \quad (6)$$

$$HV_{c_s OLC} = 16{,}264 \cdot L_l^{0,084} \cdot I_{FE}^{0,207} \cdot U_a^{0,689} \cdot V_m^{0,356} \cdot \beta^{0,101} \quad (7)$$

"Layer hardness HV" process functions for steel 42 MoCr 11:

$$HV_{a_O MOC} = 67{,}221 \cdot L_l^{0,275} \cdot I_{FE}^{0,200} \cdot U_a^{0,230} \cdot V_m^{0,263} \cdot \beta^{0,027} \quad (8)$$

$$HV_{bMOC} = 6{,}413 \cdot 10^{-4} \cdot L_l^{0,067} \cdot I_{FE}^{0,282} \cdot U_a^{3,391} \cdot V_m^{0,404} \cdot \beta^{0,037} \quad (9)$$

$$HV_{cMOC} = 0{,}055 \cdot L_l^{0,234} \cdot I_{FE}^{0,232} \cdot U_a^{2,005} \cdot V_m^{0,194} \cdot \beta^{0,118} \quad (10)$$

$$HV_{a_{s_2} MOC} = 0{,}197 \cdot L_l^{0,040} \cdot I_{FE}^{0,051} \cdot U_a^{2,102} \cdot V_m^{0,303} \cdot \beta^{0,005} \quad (11)$$

$$HV_{c_s MOC} = 166{,}002 \cdot L_l^{0,419} \cdot I_{FE}^{0,004} \cdot U_a^{0,111} \cdot V_m^{0,213} \cdot \beta^{-0,134} \quad (12)$$

These functions are the starting basis for establishing the spatial distribution of hardness by a new process function termed by the authors the "global" function, to calculate the hardness in any point of the hardened domain. In addition, based on the process functions, the effects will be determined of process parameters on hardness of HV layer.

6. CONCLUSIONS

This work focuses on the main process functions of the electron beam hardening, "layer hardness", for OLC45 and 42MoCr11 steel. These functions allow determining the effect of principal process parameters on layer hardness HV. The study results are part of a wider research work also focusing on the width and depth of the hardened layer, as well as on the spatial distribution of hardness. Identification of such technical features has a special significance for the industrial application of electron beam hardening. The limitations of this research work consist in its applicability only for experimental domain mentioned in table 1.

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