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, Vișan 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 \( x_k \), \( k = 1, 2, ..., 5 \), the following electrical-technological parameters of the process were assumed: working distance - \( L_0 \), electron beam current intensity - \( I_{Fe} \), accelerating voltage - \( U_0 \), running speed - \( V_0 \) and cross deflection angle \( \beta \). 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 and its variations” \( HV \) - 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 - \( N_p \), gas pressure within the cannon - \( P_c \), and pressure within the working chamber - \( P_t \), were kept constant.

Dependent variables. Based on the methodology proposed by the authors (Neagu 1999, Vișan 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 - \( H_t \) 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:

\[
Y = A_0 \cdot X_1^{A_1} \cdot X_2^{A_2} \cdot X_3^{A_3} \cdot X_4^{A_4} \cdot \ldots \cdot X_k^{A_k} 
\]

\[
Y = a_0 + \sum_{k=1}^{5} a_k \cdot X_k + \sum_{j=1}^{4} \sum_{k=j+1}^{5} a_{jk} \cdot X_j \cdot X_k
\]

where \( Y \) is the dependent variable, \( X_j \) independent variable and \( A_0, A_1, \ldots, A_k \) and \( a_0, a_1, \ldots, a_{jk} \) 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:

\[
HV = A_0 \cdot t_1 \cdot I_{Fe}^{A_1} \cdot U_0^{A_2} \cdot V_0^{A_3} \cdot m_k^{A_4} \cdot \beta_k^{A_5}
\]

\[
HV = A_0 + a_1 t_1 + a_2 I_{Fe} + a_3 U_0 + a_4 V_0 + a_5 t_1 + a_6 I_{Fe}^2 + a_7 t_1 I_{Fe} + a_8 t_1 U_0 + a_9 t_1 V_0 + a_{10} I_{Fe} U_0 + a_{11} I_{Fe} V_0 + a_{12} t_1 U_0 + a_{13} t_1 V_0 + a_{14} I_{Fe}^2 + a_{15} I_{Fe} t_1 + a_{16} t_1^2 + a_{17} t_1 U_0 + a_{18} t_1 V_0 + a_{19} I_{Fe}^2 t_1
\]

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.
Since the hardness values are identical in the symmetrical points as against OZ axis, we will consider only the process functions for points $a_0, b$ and $c$ and $d_0, a, b, c, d_0, a, b, c, d$, 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:

$$HV_{a_OLC} = 11,888 - L_1^{0.351} \cdot I_F^{0.322} \cdot A_u^{0.495} \cdot V_m^{0.343} \cdot \beta^{0.028} \cdot \alpha$$

$$HV_{b_OLC} = 5,481 \cdot 10^{-4} \cdot I_F^{0.084} \cdot A_u^{1.505} \cdot V_m^{0.357} \cdot \beta^{0.156}$$

$$HV_{c_OLC} = 6,596 \cdot 10^{-6} \cdot I_F^{0.107} \cdot A_u^{1.206} \cdot V_m^{0.322} \cdot \beta^{0.203}$$

$$HV_{d_OLC} = 0.391 \cdot L_1^{0.185} \cdot I_F^{0.270} \cdot A_u^{0.555} \cdot V_m^{0.381} \cdot \beta^{0.046}$$

$$HV_{e_OLC} = 16,264 \cdot I_F^{0.084} \cdot A_u^{0.207} \cdot V_m^{0.356} \cdot \beta^{0.101}$$

“Layer hardness HV” process functions for steel 42 MoCr 11:

$$HV_{a_0MOC} = 67,221 - L_1^{0.275} \cdot I_F^{0.200} \cdot A_u^{0.230} \cdot V_m^{0.263} \cdot \beta^{0.027}$$

$$HV_{bMOC} = 6,413 \cdot 10^{-3} - I_F^{0.03} \cdot I_1^{0.282} \cdot A_u^{0.391} \cdot V_m^{0.494} \cdot \beta^{0.037}$$

$$HV_{cMOC} = 0.055 \cdot I_F^{0.234} \cdot A_u^{0.232} \cdot U_2^{0.005} \cdot V_m^{0.194} \cdot \beta^{0.118}$$

$$HV_{d_0MOC} = 0.197 \cdot L_1^{0.049} \cdot I_1^{0.031} \cdot U_2^{0.102} \cdot V_m^{0.303} \cdot \beta^{0.005}$$

$$HV_{eMOC} = 166,002 - L_1^{0.419} \cdot I_1^{0.004} \cdot U_2^{0.111} \cdot V_m^{0.213} \cdot \beta^{0.134}$$

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.

7. REFERENCES


