The influence of the input parameter in case of electron beam welding

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Abstract: - Choosing an optimum working value for the electron beam welding input parameters is important both for obtaining some technological parameters and for ensuring the quality required.
Mathematical empirical modelling of experimental data allows obtaining dependent relationships between weld penetration depth and width welding and inputting parameters. This selection of the process parameters makes it possible to choose the conditions favourable for any type of material. In this paper, a model for penetration depth and weld width estimation based on the working parameters is proposed. One can study the dependence of the penetration depth (*H*) and width welding (*B*) on the process parameters so that in the end the mathematical model describing this dependence will be validated based on experimental test results.

Key-Words: - welding, electron beam process, mathematical model, penetration depth, width welding

1 Introduction

Unconventional technologies are used in the processing of many common materials, not just for those with special properties. In many cases, due to the large volume of material that can be processed in a certain unit time these processes are more effective in comparison to classical processes, which imply a major consumption of energy and tools. In most of these new processes, energy and tools consumption is reduced or almost zero, some tools having high durability, as the processing electrochemistry, beams of electrons or ions, laser etc.
The main processes that are based on the use of electron beam are: welding, drilling, hardening and heat treatment. Such processes are only part of many processing procedures based on the applications of electron beam. The process of electron beam welding is a method of making fusion weld; the heat is generated at the impact of an electron beam of high energy with the working pieces to be joined. This method produces deep welds without adding overly heat that can disadvantageous affect the properties of the surrounding metal.
In the field of electron beam welding, the specialized literature is vast and covers up the research in the filed. Regarding the aspect mentioned in his paper, *Koleva* in 2005, [1] connected the electron beam welding parameters to the improvement of the process thermal efficiency. *Chi in 2008,* [2] analyzed the influences of electron beam welding parameters on weldments strength and defect formation in case of AZ-series magnesium alloys.
Items related to heat-affected zone have been clarified in his work by *Richards* in 1994, **[**3]; these aspects regard the influence of electron-beam welding parameters on heat-affected-zone in case of INCOLOY 903, especially in case of microfissuring apparition. A process model for the heat-affected zone microstructure evolution in duplex stainless steel weldments was realised by *Hemmer in 2000,* [4].
The effects of electron beam focusing characteristics on fusion zone are analytically investigated by *Ho in 2005* [5]. The paper analyzed the weld quality during electron beam welding depending on beam power, welding velocity, and focusing parameters.
There are different researches connecting the weld penetration depth of linear energy, the speed of welding or theoretical relationships which attach an expression for determining the approximate relationship. Many studies associate the weld penetration with welding speed and focus on the effect of welding speed to penetration depth under conditions in which other parameters are kept constant, but do not take into account interactions between factors.
In this way fewer issues addressed are related to the parameters dependence on the working parameters of the output process, requiring a relationship of this dependency.

2 Input parameter after systemic approach

The main electro-technological parameters characterising electron beam welding process, according to their extent of interference in the welding process, may be the following [6, 7]:

a. The parameters related to the electron beam: - accelerating voltage, U_a; - beam current, I_f; focusing current, F; beam diameter, d;
b. The parameters characteristic to the welding features: the type of the material, thermo-physical and chemical features of the material; workpiece thickness;
c. Other parameters: welding speed, v; focal distance, d_t (the distance from the inner surface of the gun to welded workpiece); vacuum pressure in the electronic gun chamber cannon P_t; vacuum pressure of the welding chamber P_s, preheating temperature, Tpr; heat treatment after welding.
Starting with this theoretical consideration, the necessity to attach a particular working condition is imposed. Choosing the technological parameters is a basic problem of further conducting the experiment. The correct choice of these parameters depends on the ability to reflect the most important phenomena of the technological process studied. When one chooses the input parameters one should take into consideration the possibility to easily change and measure them, their ability to significantly influence the process being also important. Furthermore, these factors should not have functional dependencies between them.
Establishing the dependent parameters, which depend on the entire structure of the experiment, is based on the optimization objectives pursued, as the strategy for obtaining the mathematical model. They represent the output values and are generally economic parameters (productivity, quality, and cost) or parameters concerning the operating behaviour of the product (figure 1) [8, 9, 2].
Analyzing and synthesizing the amount of information available on the electron beam process, one may form a clear idea of the processing operation as a whole, but for the achievement of experiments one should neglect certain parameters, in order to obtain a better productivity of the process and to keep the focus on the direction of interest.
The variation of the process parameters has a distinct and complex influence on the electron beam machining process products.
The systemic models for the electrons-material interaction allow establishing the main parameters for each application (accelerating voltage, focus current, processing speed etc.) and by these factors an efficient control in processing time. Thus, the systemic approach gives the possibility to modify the specific parameters, and also to obtain the convenient results.

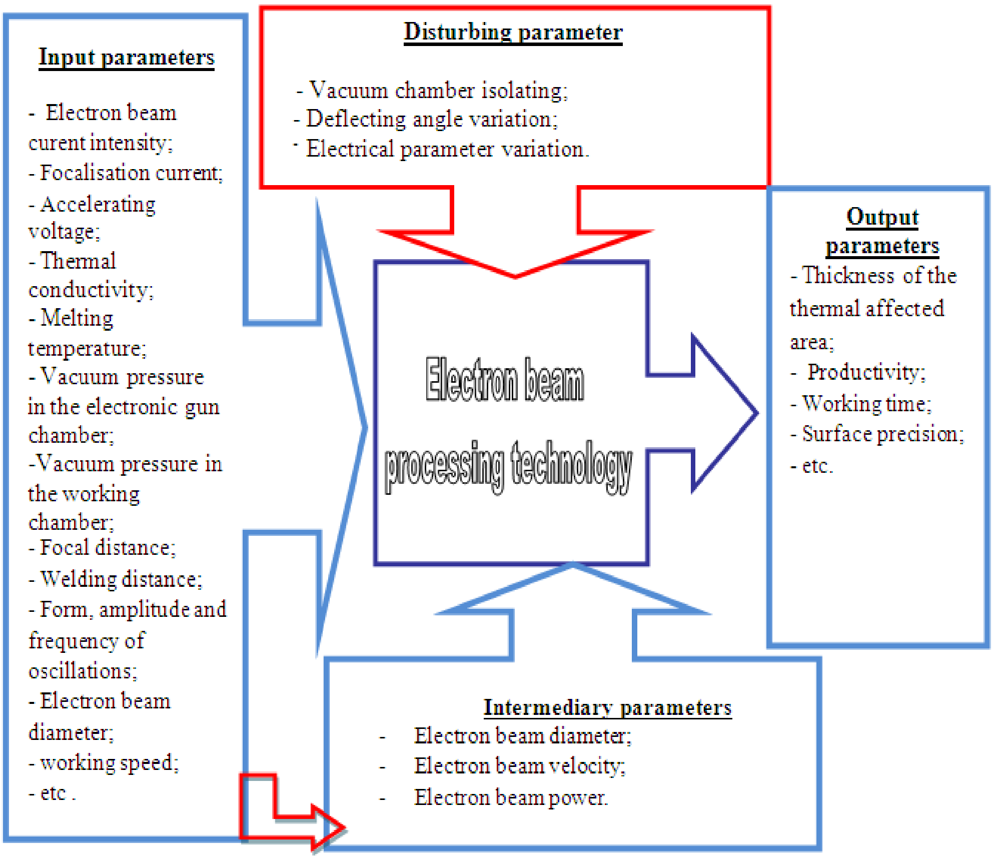

Fig.1. Electron beam process parameter

The initiation of some research regarding the electron beam welding has requested an analysis of the process conditions. The specific knowledge has allowed development of a graphical representation designed to reveal the parameters of interest in electron beam welding and the factors that influence these parameters.

Thus, the proper choices of the input parameters are important for the successful application on electron beam welding process.

3 Experimental research

The proposal for this paper implies obtaining an objective function of the parameters output from the input process that connect width and penetration welding with the working regime and default of technological parameters of the processing equipment.

The specimens were made from steel with little percentage of carbon with the chemical composition presented as following: 0.112 % C, 0.048 % Si, 0.58 % Mn, 0.014 % P, 0.032% S, 0.166% Cr, 0.026% Mo, 0.108% Ni, 0.039% Al, 0.011% Co, 0.189% Cu, 0.003% Nb, 0.001% Ti, 0.004% V, 0.010% W, 0.004% Pb, 0.016% Sn, 0.003% As and 98.649% Fe.

The equipment used was ELA 60/60 (AFE) welding equipment fit out with a vacuum system and a working chamber. The technical characteristics of the equipment imply an accelerating voltage of 60 kV, the current intensity, measured in mA, between 5 and 1000, the focusing current from 400 mA to1000 mA, and the pressure in the electron gun chamber, Pa (mm Hg) - 10.7 * 10-3 (8 * 10-5).

In this study one used an accelerating voltage of 60 kV and two values for beam current: 150 mA and 250 mA. The vacuum of the work chamber was better than Pa (mm Hg) – 10. 7*10-3 (8*10-5)

In order to obtain the model proposed in the practical realisation of the experimental research, in carrying out the experimental tests one took into account, in the choice of input parameters, the process of preliminary tests, which revealed the levels of each factor, for which the simulation software specialist EBSim was used; furthermore one needed to consider the technological possibilities of the welding beam electron equipments, as well.

According to bibliographical references in this field of activity, the thermal energy or the thermal energy quantity transferred to the workpiece varies according to four basics parameters: the number of electrons that reach the workpiece in a certain unit of time (beam focusing current F); the electron velocity (accelerating voltage U_a); beam current (I_f); welding or working speed (v.)

Following this analysis, the factors' change during the process can be observed in Figure 2. Parameters that remain constant and the main input parameters and values for this parameters can be seen in Table 1.

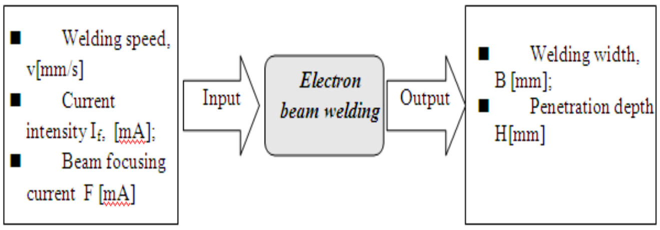

Fig.2. Electron beam welding parameters

Table 1. Factor levels in the experimental program for the electron beam welding

No.	Parameter (unit)	Levels	
		1	2
1.	Beam current I_f (mA)	150	250
2.	Welding speed (mm/s)	3.83	12.5
3.	Accelerating voltage U_a (kV)	60	-
4.	Focusing current: F (mA)	744	740
5.	Working distance (focal position): dl (mm)	150	-
6.	Work chamber pressure: P_i (Pa)	$10.7*10^{-2}$	-
7.	Workpieces material (% C)	0.112	-

Establishing the analytical size-dependence of the penetration depth H and welding width B and the parameters of (I_f, v and F) means finding a method which, based on a series of measured values of the two output variables, should allow a general relationship between them.

The choice of regression equation is based on some theoretical considerations or on the graphical representations of experimental data.

4 Results and discussion

Using the experimental data obtained, polynomial regression models for the behaviour of weld penetrating depth (H) and weld width (B) are found. These two output parameters depend on various factors, such as beam power (through beam current and acceleration voltage), welding velocity, position of the focus of the beam towards the welded material surface, the vacuum pressure, the welded material etc.

The variation law of input factors in the process (recurrence relations) can be written as a matrix (proposed by Vigier) but also by using the method of least squares it can be written in the form of relations 1-7.

The penetration depth is an important factor critical to the quality of an electron beam weld

$$H = -144.143 + 0{,}137 \cdot I_f - 26.346 \cdot v + 0.218 \cdot F \qquad (1)$$

$H=5.805 \cdot 10^{-20} \cdot I_f^{1.273} \cdot v^{-0.537} \cdot F^{6.101}$ (2)

If the focalization current (*F*) is maintained at a constant value (744 mA) the regression function has the main expression:

$H=0.201 \cdot I_f^{0.04} \cdot v^{-0.509}$ (3)

For the welding width the mathematical model is:

$B= - 57.17 + 0.0135 \cdot I_f - 6.731 \cdot v + 0.092 \cdot F$ (4)

$B=1.892 \cdot 10^{-17} \cdot I_f^{0.216} \cdot v^{-0,286} \cdot F^{5.957}$ (5)

$B=- 15.767 + 0.135 \cdot I_f + 5.855 \cdot v$ (6)

$B=0.982 \cdot I_f^{0.33} \cdot v^{-0.627}$ (7)

The models 1-7 are used for a visualisation of the relationships between the main parameters considered.

Conclusions from analysis of determined empirical functions. As expected, the empirical functions determined emphasize the increase in the depth of penetration and weld width along with an increase in intensity value of the I_f current electron beam (Fig.3 and Fig.4), this fact being revealed by the positive value of the exponent I_f in the power type relations. Indeed, with increasing intensity of the beam current, there is a greater transfer of energy and the area affected by the melting (and in which structural transformations take place) is greater**.**

On the other hand, increasing the speed of welding means that the maintaining time of workpiece under the electron beam action is lower and, as such, the penetration depth and width of welding bath will have a lower value, the situation being suggested by the negative exponents of the corresponding parameter *v* in the empirical power type relations. One should also observe that the corresponding exponent I_f, the current intensity of electron beam, is smaller in absolute value than the exponents attach to the welding speed *v*, which means that the influence of intensity I_f current is less than that exerted by the speed welding *v*, as it can be ascertained from the analysis of power functions.

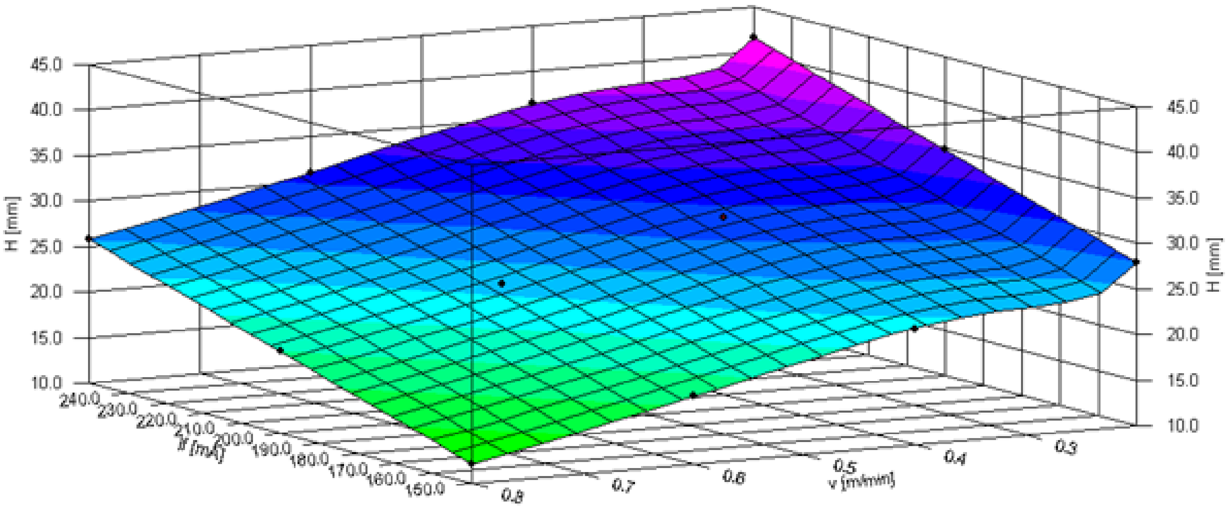

Fig.3. Penetration depth depending on current intensity and welding speed

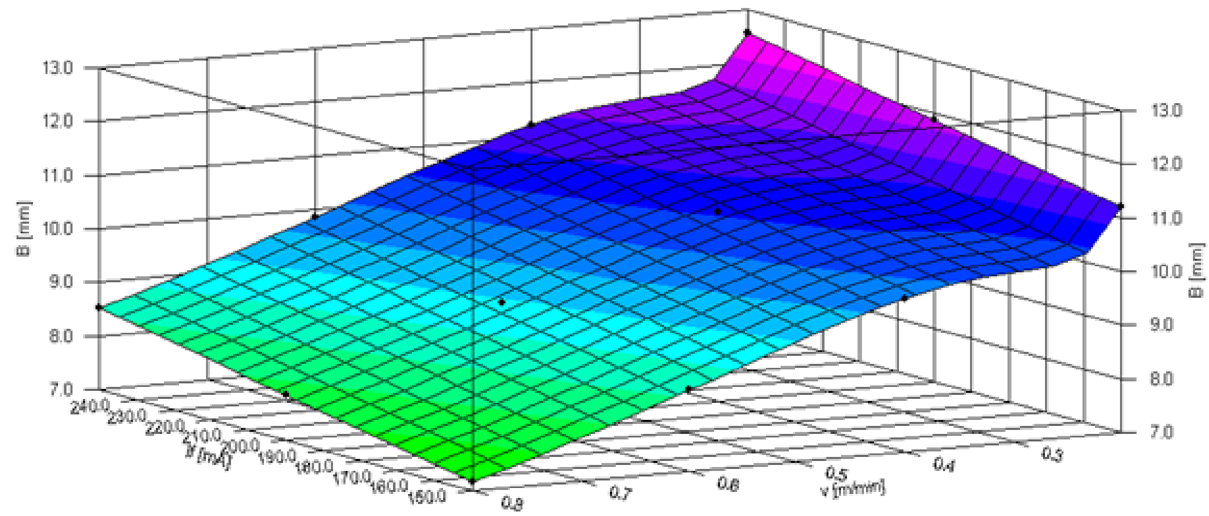

Fig.4. Weld width depending on current intensity and welding speed

Should one take into consideration and analyze the dependence relation and the power expression, the most important parameter is beam focusing current since it has the highest exponent.

If one examines the cases and steels with a less percentage of carbon and a steel with 0.45% of C, which is expected to be primarily a difference between the carbon content, one finds out that in case of the penetration depth the exponents attach to *v* and I_f parameters are larger in absolute terms in the second analysed case, which could justify the decrease in melting temperature of steel, with increasing carbon content. This heat affected area (HAZ) is small in the studied case, ranging between 0.02-0.06 mm.
In the case of steel with small percentage of carbon, in the weld area and heat affected zone, the granular value is smaller than for other classic welding processes. There is no danger of split in the cold, so-called split by hardening, due to reduced quantity of heat introduced during the welding process and to high speed of heating and cooling. The structure of the weldments of common steel is similar to that of carbon steel; however, one can notice more Fe a, because lower quantities of carbon are present. Melted zone is characterized by a scratchy structure of similar structural composition but with a much less grainy value and, as we mentioned, the heat affected zone is small.

5 Conclusion

In this paper the electron beam welding process for common steel has been modelled by using the least squares method. These approaches are used in an attempt to determine a regression function between the inputs and outputs of the welding process.
Following the systemic study conducted [1, 3] there were chosen main parameters that define the process of electron beam welding which were further on used in the research program to determine the process functions such as *H* and *B* for a common steel with a little percentage of carbon, while other parameters were maintained at a constant value.
By following this analysis one considered that as the input of various parameters, the most important influence on the main features of the process parameters are the current intensity I_f , welding speed *v* and focusing current *F*.
- The various welding speeds will have different effects on welding geometry (*H* and *B*); by increasing the welding speed, the value of the welding decreases.
- The experimental data have shown that the penetration depth of an electron beam into a workpiece is influenced by several factors. In order to achieve the weld criterion the beam must completely penetrate the workpiece, in which case the energy to do the welding, the speed and focusing current were significant.
- Relative to the previous expression, the impact of the beam current (current intensity) is significant on the weld characteristics but the welding speed seams to be more important than all the other factors considered. For the results, it has been observed that the penetration depth increases with the increase of the current intensity value.

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