Some phenomena regarding the superficial layer in case of the electron beam process

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ABSTRACT: The electron beam that melts the workpiece surfaces, acts as concentrated energy tool. Starting from this consideration, we have analyzed some hypotheses regarding the energy flux distribution at the electron beam impact zone with the workpiece surfaces. Some hypotheses about the energy flux distribution on the workpiece surfaces are presented in this paper. It is well known that in the welding processes, a melting zone called welding bath appears in the workpiece material. The thermal flux density has different expressions for the heating process, the melting process and for the phase transformation process depending on the type of the energy source. At low voltages, the electron beam represents a superficial thermal source; the increase of the voltage will determine also the growth of the penetration depth, therefore the electron beam becomes a thermal volume source.

Key words: electron beam welding, heat affected zone, kinetic energy

1 INTRODUCTION

Due to present industrial technological requirements, the nonconventional technologies were applied more and more often. Compared with traditional machining processes, nontraditional machining processes are characterized by higher power consumption due to a higher material removal rate. The advantage of nonocnventional manufacturing processes is that we can obtain a better quality of the workpiece surfaces and small residual stresses.

The electron beam manufacturing process is based on an extremely high kinetic energy density, created by a stream of focused high velocity electrons, which bombard and locally vaporize the workpiece material.

Among the processing methods using the electron beam, we could mention drilling, welding, surface cleaning and degasification, the superficial heat-treating (annealing, quenching), surface micro-alloying and coating (or plating) by melting, doping, electron beam metalizing, electronolithography etc.

In particular, the electron beam welding is a technology used to obtain welded constructions with important advantages, such as deep and narrow defect-free welds, minimal heat affected zone, as well as a high joining rate. A imagine of the number of technical articles in witch this method's evolution in time is mentioned, is presented in the figure 1.

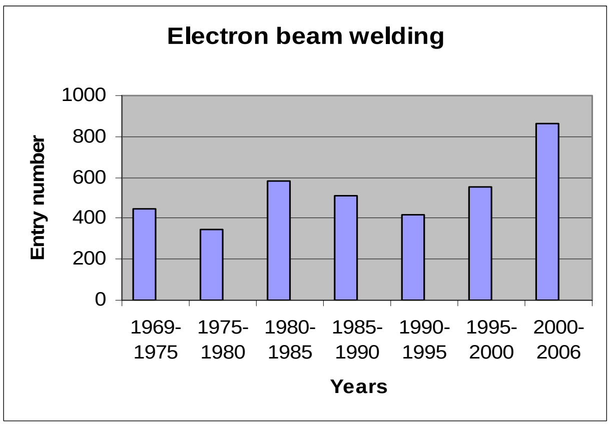

Fig. 1 Evolution of electron beam welding

After analysing figure 1, we can notice that in time, the researcher's concern regarding the electron beam welding process is relatively constant.

2 THERMAL BALANCE ANALYSIS

In the welding processes it is well known that in the workpiece material appears a melting zone called *welding bath*. The thermal flux density has different expressions for the heating process, the melting process and for the phase transformation process depending on the type of the energy source.

The electron beam represents a superficial thermal source at low voltages; the increase of the voltage will determine also the growth of the penetration depth, so that the electron beam becomes a thermal volume source [2].

In figure number 2 it is presented an eloquent example of the welding aspects that are depending of some input parameters.

Fig. 2 Weling's aspects

When the welding process is using intense/high working values a crater (key zone) appears and the melting material flows, due to the insufficient superficial tension. Also, the coefficient of vaporization value grows and the welding penetration exceeds the limits of the workpieces (fig. 2).

If we analyze the case of complete penetration, the welded joints may sometimes present a uniform protuberance on the root of welding. The protuberance breadth depends on the electron beam welding parameters. Some hypotheses regarding the shape of these protuberances (key form) are establishing the way the electron beam energy is distributed [4, 5].

The depth of the electron beam welding penetration depends on the following parameters: the material thickness, welding material type, electron beam strength, welding speed, the diameter of the electron beam, determined by the focalization conditions.

The impact of the electron beam with the welded surfaces determines some very complex interaction processes that are depending on the electron kinetic energy transferred to the workpiece, simultaneously, with electron breaking, deviation, and finally blocking this electrons at a depth δ, determined previously [1, 3].

When an electron beam – worpiece material collision takes place, the electron beam penetrates the workpiece material and only a reduced number of electrons can escape.In the impact zone, the electron beam – workpiece interaction determines the apparition of an energetic exchange.

The emitted electrons are thermal electrons that have a small eV energy value, due to the temperature of the bombarded piece and to the secondary electrons that can also reach several tenth of eV.

The energy that is absorbed by the material participates to:

- the material heating, that transform the electron kinetic energy into heat. Thus, these processes allow us to effectuate some other processing methods using the electron beam such as welding, perforating etc.
- producing the X Raze. Although the performance rating to produce X Raze is low (only 55 %) in the case of an electron beam accelerated with 100 kV., on wolfram material, protection is required [4, 6, 7].

One of the problems that we will focus on in this paper aims the phenomena that take place at the superficial layer, in the impact zone between the electron beam and the workpiece. These phenomena help us distinguish between different electron beam manufacturing processes. Therefore, the electron beam penetration depth into the workpiece reveals different manufacturing procedures, depending on the type of penetration: a superficial one, at the surface of the material, or melting and even vaporizing of the workpiece. Depending on the current's intensity, when an electron beam type of manufacturing is used, we are interested in the melting process of the metal to be welded, not the vaporization. In the actual accessible specialty literature, there is no specific information exact enough regarding the values and consequences of the caloric energy developed in the impact area, consequences such as: vaporization, melting, structural modifications, and thermal induction.

Taking into considerations the above mentioned aspects we can formulate the hypotheses that the electron beam energy value must be equal with the

one of the energy required in the welding process.
The thermal flux density generated by the electron beam is used completely in the heating phenomenon and in the phase transformation process, as some researchers appreciate. We consider that some energetically loses occur in this process. Thus, if we take into consideration that the electron beam energy is equal with the energy consumed in the welding process, we can write:

$$E_c = W_u \tag{1}$$

where E_c is the kinetic energy of the electron beam and W_u is the useful energy in the welding process.
The necessary energy for electron beam welding can be considered as a sum of different energies that characterize the phases of the electron beam machining process:

$$W_u = W_1 + W_2 + W_3 + W_4 + W_5 + W_6 \tag{2}$$

where W_1 represents the energy necessary to heat a certain quantity of material without any phase transformations in the workpiece material, W_2 is the energy used to heat a volume of material which is affected by phase transformations, W_3 is considered to be the energy necessary to heat/ bring the material until the melting point, W_4 – the energy used for effective melting of the same volume of material, W_5 - necessary energy to vaporize the melted material.
Each of these energetic components can be described with different theoretical expressions. Thus, the energy W_1 used to heat a certain quantity of material without any phase transformations in the workpiece material is:

$$W_1 = mc(\theta_{fmf} - \theta_i) \tag{3}$$

where m is the mass of the heated material [g], c – the thermal capacity of the workpiece material, θ_{fmf} is the temperature reached by the workpiece material without any phase transformations, Θ_{i} – the initial temperature of the material.
The energy used to heat a volume of material affected by the phase transformations is:

$$W_2 = k_1 mc(\theta_{tf} - \theta_{fmf}) \tag{4}$$

k_1 being a coefficient that takes into consideration the fact that not all the heated material will have the phase transformations (k_1<1), Θ_{tf} - the temperature reached by the material affected by the structure modifications due to phase transformations.
The energy W_3 necessary for bringing the material to the melting point is given by:

$$W_3 = k_1 k_2 mc(\theta_t - \theta_{tf}) \tag{5}$$

where k_2 is a coefficient that takes into consideration the fact that not all the heated material is melted and Θ_{t} is the melting point of the material.
The energy W_4 necessary to effectively melt of the quantity m of material is:

$$W_4 = k_1 k_2 m \lambda_t \tag{6}$$

where λ_{t} is the specific melting point of the material.
To bring the material from the melting stage in the vaporizing stage, a quantity W_5 of energy is necessary:

$$W_5 = k_1 k_2 k_3 mc(\theta_v - \theta_{fmf}) \tag{7}$$

where k_3 is the coefficient that takes into consideration the fact that not all the melted material reaches the vaporization temperature. The vaporization of the workpiece material is not desired; the ideal is to be null or minimum, but the researchers appreciate that even in the case of electron beam welding a vaporization of a small quantity of material exists.
We can consider that the energy consumed for the vaporization of a quantity of the melted material is:

$$W_6 = k_1 k_2 k_3 m \lambda_v \tag{8}$$

where λ_{v} is the vaporization specific temperature.
Practically, in the electron beam welding process, this energy must be close to zero. In some cases when the power of the electron beam is not adequate to the thickness of welding material, vaporization appears.
Taking into consideration the above mentioned aspects and the relations (3) to (8), we can write the following expression for the useful energy in the electron beam welding process case:

$$\begin{aligned} W_u &= mc(\theta_{fmf} - \theta_i) + k_1 mc(\theta_{tf} - \theta_{fmf}) + \\ &+ k_1 k_2 mc(\theta_t - \theta_{tf}) + k_1 k_2 m\lambda_t + \\ &+ k_1 k_2 k_3 mc(\theta_v - \theta_{fmf}) + k_1 k_2 k_3 m\lambda_v \end{aligned} \tag{9}$$

To write the complete thermal balance equation of the electron beam machining process, we have to emphasize the fact that a part of the energy is spreaded in the vacuum medium through some

radiations, so called losses.
After equalizing the relations of the two types of energy (the electron beam energy and the energy of working) and taking into consideration the lost energy we obtain:

$$\frac{mv^2}{2} = mc(\theta_{fmf} - \theta_i) + k_1 mc(\theta_{tf} - \theta_{fmf}) + \\ + k_1 k_2 mc(\theta_t - \theta_{tf}) + k_1 k_2 m\lambda_t + \\ + k_1 k_2 k_3 mc(\theta_v - \theta_{fmf}) + k_1 k_2 k_3 m\lambda_v + P \tag{10}$$

As we can see, after analyzing the last relation, the presented model shows that not all the energy of the electron beam is used on melting and, after joining the materials of the workpieces, a part of this energy is used to heat (not only the melted material, but also the zones placed near the melted material).
These loses are caused especially by the backscattered electrons and by the Roentgen radiation and depend on the type of the welding material and some input parameter.
If we take in consideration the above mentioned hypotheses, a thermal welding electron beam efficiency (η_t) is defined as a ration between the energy absorbed by the welding components (in our case the useful energy) and the electron beam energy depending on the main workpiece proprieties (the atomic number).

$$\eta_t = \frac{W_u}{E_c} = \frac{mc(\theta_{fmf} - \theta_i) + k_1 mc(\theta_{tf} - \theta_{fmf})}{\frac{mv^2}{2}} + \\ \frac{k_1 k_2 mc(\theta_t - \theta_{tf}) + k_1 k_2 m\lambda_t + k_1 k_2 k_3 mc(\theta_v - \theta_{fmf})}{\frac{mv^2}{2}} \\ + \frac{k_1 k_2 k_3 m\lambda_v + P}{\frac{mv^2}{2}} \tag{11}$$

We notice that there are many factors able to influence this process and in the future, we will try to verify the mathematical model using the experimental research values.
The relevance of the introduction in this relation of the thermal efficiency is emphasized by some researches in the field that have related the thermal efficiency with the welding parameters [2, 6]. The goal of our investigations was to achieve the value of the k_1, k_2, k_3 coefficients.

3 CONCLUSIONS

Different materials welded joining find their applicability in numerous industrial areas, for both technical and economic reasons, the caloric energy distribution developed in the impact zone is important to evaluate, especially due to the technical difficulties that appear when welding non-similar materials and especially to the metallurgic incompatibilities. The percentage value of the coefficients k_1, k_2, k_3 can give a partial solution to the analyzed problem. In the future we plan to extend the theoretical and experimental research so that we will improve the mathematical simulation of the phenomena that occur in the impact zone between the electron beam and the workpiece superficial layer. The influence exerted by one of the main work condition regarding the surface dimensions affected by the electron beam will be considered.

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REFERENCES

1. J. A. McGEOUGH, *Micromachining of Engineering Materials*. New York – Basel: Marcel Dekker, Inc., 2002.
2. E. KOLEVA, G. MLADENOV, K. VUTOVA, *Calculation of weld parameters and thermal efficiency in electron beam welding.* Vacuum 53 (1999) 67 – 70.
3. A. NANU, et al *Tratat de tehnologii neconvenţionale*. vol. I, Editura Augusta, Timişoara, 2003.
4. I. MAGNABOSCO, P. FERRO, F. BONOLLO, L. ARNBERG, *An investigation of fusion zone microstructures in electron beam welding of copper–stainless steel.* Materials Science and Engineering A 424 (2006) 163–173.
5. J.F. Oliveira Santos, L. Quintino, Processamento de materiais por feixe de electrões laser e jacto de água, ©ISQ – 1991, Publicação do ISQ – Instituto de Soldadura e Qualidade, pg.15 – 71.
6. N. RYKALIN, A. UGLOV, I. ZUEV, A. KOKORA. *Laser and electron beam material processing*. Moscow: Mir publishers, 1988.
7. S. ROUQUETTE, J. GUO, P. LE MASSON *Estimation of the parameters of a Gaussian heat source by the Levenberg – Marquardt method: Application to the electron beam welding.* International Journal of Thermal Sciences 46 (2007), 128–138.