MATHEMATICAL MODEL OF THE ELECTRIC ARC. THE IMPACT OF THE WELDING ARC AND THE CALORIC POWER ON THE WELDED SEAM.

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ABSTRACT: This paper present the algorithm for calculating the electric arc as a heat source in the arc welding processes, but also the dependence between it and the calorific value developed, because the quality of welded seams has a decisive influence in terms of reliability of welded structures.

KEY WORDS: electric arc, microscopic model, shielding gas.

1. INTRODUCTION

It is known that, when welding in a shielding gas medium, MAG, the types of electric arc are distinguished based on the transfer mode depending on the caric power developed by the electric arc arc [1],[3].

In the column of the electric arc the carriers free of electric charge are, both the electrons, having the electric charge, $q_e = -e$ and concentration n_e, but also positive or negative ions, usually monovalent, having electric charge, $q_i = e$ end concentration n_i. [2], [7].

Among the main sources of free carriers of electric charge, we can mention the following processes that occur in the electric arc column:

-thermal emission and emission due to the electric field of an electrode;

-photoionization and ionization above the metastable level, which takes place in the electric arc column [5].

It is very important that when we want to optimize the welding process, to know the mathematical model as accurately as possible, of the analyzed phenomenon. The evolution of the whole analysis depends on the mathematical model and implicitly on the set of process variables [1].

2. MATHEMATICAL MODEL

If a complete ionization with the electric arc column is considered, we obtain:

$$n_e = n_i = n \qquad (1)$$

It is shown that the dependence of the concentration n, of electrons or ions, on the temperature T, from a certain point of the column is given by the relation:

$$\mathrm{n} = \frac{2p^{1/2}(kT)^{1/4}(2\pi m_e)^{3/4}}{h^{3/2}}\exp\left(\frac{-eU}{2kT}\right) \qquad (2)$$

where:
p - pressure;
k - constant Boltzman;
h - Planck's constant;
m_e, e - the mass of the respective electron the elementary electric charge;
U - the voltage (potential) of ionization of the medium in the electric arc column. [4], [8].

According to the natural tendency of any system to evolve towards a state of equilibrium, there is a shift of both electrons and ions in the volume of the electric arc column from the areas where we, respectively have higher values, to those where they have values lower. The tendency is to achieve an equalization of the concentrations of electrons, respectively ions, in the whole space occupied by the electric arc column.

Thus, in the column of the electric arc appears a current of electrons, respectively ions, which is called the diffusion of electrons, respectively the diffusion of ions in the volume of the column. [7], [9].

The diffusion being an ordered motion, in the column of the electric arc appears an electric current of diffusion of density electrons $\overline{J}_{De}$ and an ion diffusion current with density $\overline{J}_{Di}$.

As a characteristic quantity for diffusion, at each point of the electric arc column, the density of the electron flux is defined, denoted by $\overline{j}_e$, respectively ion flux density, $\overline{j}_i$ as the number of particles that, in the unit of time, pass through the unit of surface, considered around that point, in a well-specified direction.

Compared to such a reference system, the column of the electric arc, as a whole, is at rest, by which it must be understood that its center of mass is immobile.

The consequence is that, in this case, the convective components do not intervene in the time-related derivatives of the quantities, which would appear if the respective equations were written with respect to a reference system in relation to which the spring column, as a whole, would be in motion, that is, its center of mass would move at a certain speed.

In conclusion, the derivative with respect to time of any state quantity is reduced to the derivative, generally partial, of that quantity with respect to the moment t.

It should also be noted that all equations are established for a material volume in the column of the electric arc, which will be noted with Ω*, coincides with the control volume, denoted by Ω, which is fixed in relation to the chosen reference system. For this reason, all equations will be established for the control volume Ω, whose volume element will be denoted by dΩ.

The first continuity equation is obtained by applying the law of conservation of free electric charge, for the control volume, which, in global form, is expressed by the relation:

$$\int_{\Omega} div\overline{J}d\Omega = -\frac{d}{dt}\int_{\Omega} qd\Omega \qquad (3)$$

However, as a whole, the spring column is electrically neutral.

A second continuity equation is obtained by applying the law of conservation of mass for the control volume Ω, in a source well:

$$div(\rho_d \overline{v}_m) + \frac{\partial \rho_d}{\partial t} = 0 \qquad (4)$$

The third continuity equation is obtained by applying the law of conservation of the number of electron particles, respectively of ions, for the considered control volume.

For any point in the electric arc column, this conservation law is written:

$$\frac{\partial n_e}{\partial t} = -div(D_e gradn_e) + G_e - R_e \qquad (5)$$

$$\frac{\partial n_i}{\partial t} = -div(D_i gradn_i) + G_i - R_i \qquad (6)$$

Where:

G_i, G_e are the volume densities of the generation speeds of electrons, respectively ions and represent the number of electrons, respectively ions generated in the unit of time and in the unit of volume around the considered point;

R_e, R_i are the volume densities of the recombination rates of electrons, respectively ions, and represent the number of electrons, respectively of ions, which recombine, in the unit of time, in the unit of volume, around the considered point. [5], [6].

Because, energy transformations take place in the ionization process, which occurs in the electric arc column, a first conservation equation is obtained by applying the principle of energy conservation for the control volume. Thus, the energy developed in the unit of time in the control volume Ω, covers the variation in the unit of time of the internal energy in Ω.

Based on the above, for any point in the column of the arc, we obtain the equation:

$$(\overline{J}_e+\overline{J}_i)\cdot\overline{E}=\rho_d c\frac{\partial T}{\partial t}-div(\lambda gradT)+P_R+eU_i\frac{\partial n}{\partial t}-div(U_i\overline{J}_e) \tag{7}$$

Where: P_R is the power radiated by the unit of volume around the considered point, c is the specific heat, and the other quantities have the meanings specified so far.

A final equation is obtained by applying the second principle of dynamics for the considered plant volume.

Considering the more general case when, in the electric arc column, in addition to the electric field of intensity $\overline{E}_1$ there is also a magnetic field of intensity $\overline{B}$ and neglecting the gravitational forces [10], for any point in the column of the electric arc, we obtain:

$$n_e m_e\frac{\partial\overline{v}_e}{\partial t}=-n_e e(\overline{E}+\overline{v}_e\times\overline{B})-\nabla p+\overline{P}_{ei} \tag{8}$$

$$n_i m_i\frac{\partial\overline{v}_i}{\partial t}=-n_i e(\overline{E}+\overline{v}_i\times\overline{B})-\nabla p+\overline{P}_{ie} \tag{9}$$

With the help of these equations you can calculate exactly all the quantities and with them you can completely describe the operation of the electric arc, if you know the limit values, the material properties depending on the temperature and the values of some of the process quantities. How these values, which generally depend on the temperature T, the pressure p, the intensity of the electric field $\overline{E}$, are imprecisely known, the solution of this system is generally not possible [6], [7].

3. WELDING ELECTRIC ARC SIMULATION

If the electric arc is analyzed only as a thermal source, when welding two components of S235 Steel sheet, depending on the calorific value developed during the welding process, two variants are taken into account.

In the first variant, the electric arc is regarded as a medium, located at a constant temperature, without thermal inertia, which develops heat through the thermal effect of the welding current, which it transmits, through thermal conduction to the components and the electrode wire.

In the second variant, the thermal inertia as well as the temperature dependence of the material properties for the electric arc are also taken into account.

In the case of the first variant, the processes are studied separately.

First, the specific calorific value, at constant temperature, which is used as a load for thermal analysis, is determined.

The analysis of electrical conduction aims precisely at determining the specific caloric power.

The analysis was performed for two electric arc temperatures, of 15000K, respectively of 25000K, for which the values of electrical resistivity were chosen from the previous table, $7\cdot10^{-5}$ respectively, $3{,}5\cdot10^{-5}$ Ω·m.

Given that the largest share is the heat developed in the electric arc, for components and electrode wire the value of electrical resistivity was chosen corresponding to the highest temperature, for which data are available, is $r_{sv}=12\cdot10^{-7}$.

The current density distribution obtained for the two cases is shown in Figure 1.

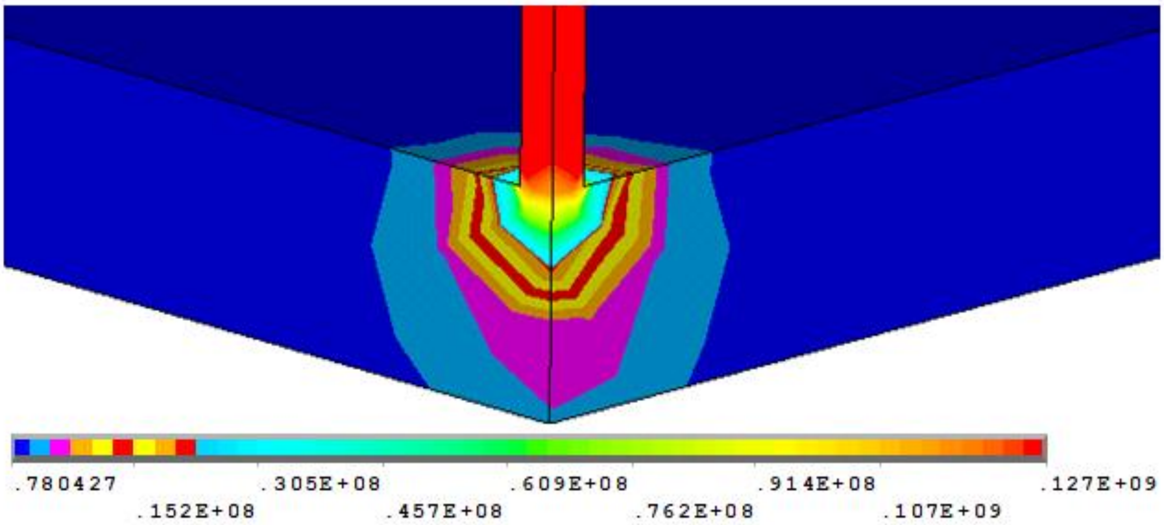

Figure 1. Current density distribution

The intensity of the welding current was defined as a load, through the upper surface of the electrode wire, at the value of 98.75 A, because a model reduced to 1/4 is used.

As a boundary condition, the value zero was imposed for the electric potential on the lower surface of the components, which, moreover, are connected to ground.

Because the power supply is direct current, the analysis of the electrical conduction is performed for a steady state.

Figure 2 shows the variation of the current density along a line passing through the axis of symmetry of the electric arc, depending on the distance measured from the lower surface of the components.

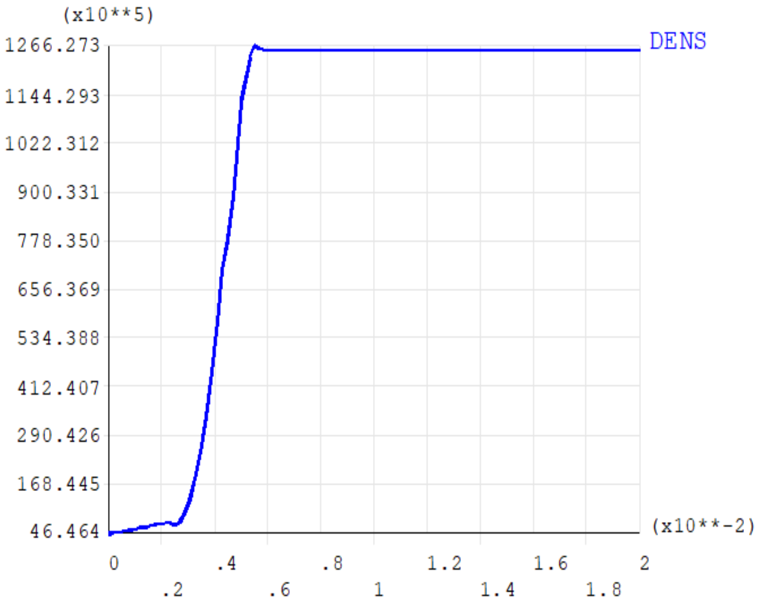

Figure 2. Current density distribution along a line passing thoughbthe axis of symetry

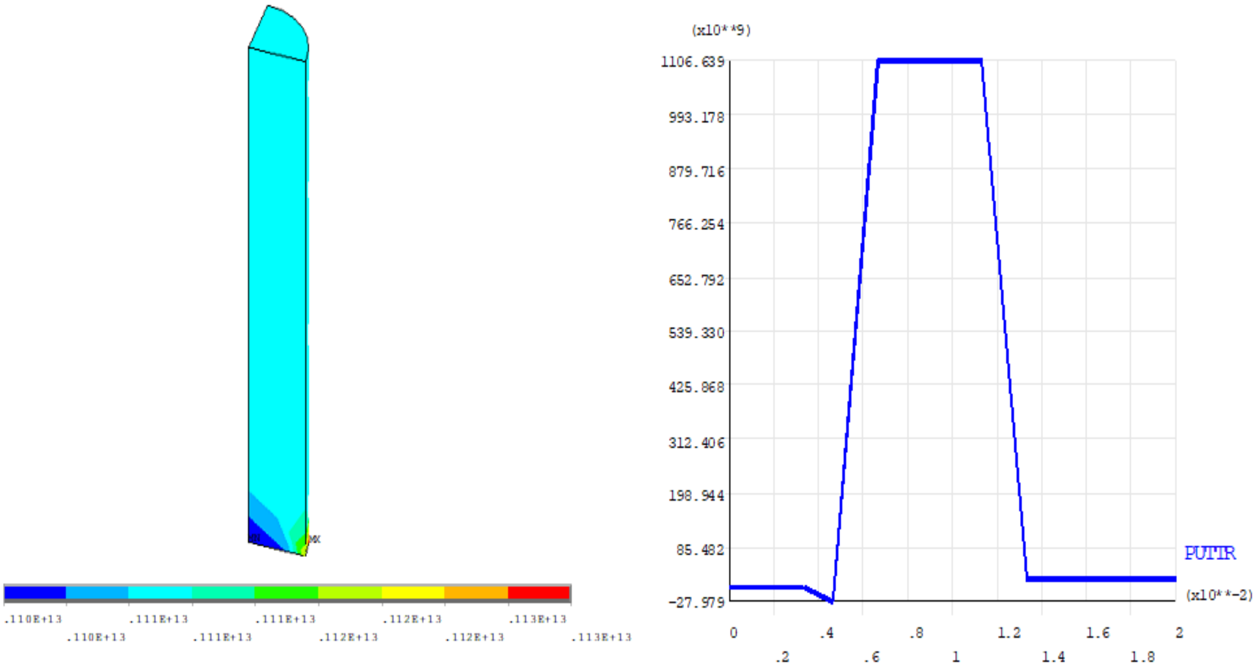

Figure 3. Distribution of calorific value in the electric arc column. T=15000^{0}K

It is observed that the current density has the maximum value, constant, equal to 1,25·10^8 A/m^2, respectively 125 A/mm^2, in the electric arc column, value that corresponds to the one indicated in the specialized literature, as well as to the calculated one.

The distribution of the specific calorific power in the electric arc column, as well as its variation with the distance, along the mentioned line for the two cases, are shown in Figure 3, respectively Figure 4 for T = 25000^{0}K.

The maximum value of the specific calorific value intervenes in the column of the electric arc, and rises to 1,1·10^{12} W/kg, for the first case, respectively at 5,9·10^{11} W/kg for the second case.

It is observed that also in terms of specific calorific value, the values closest to those given in the literature are obtained for the second case.

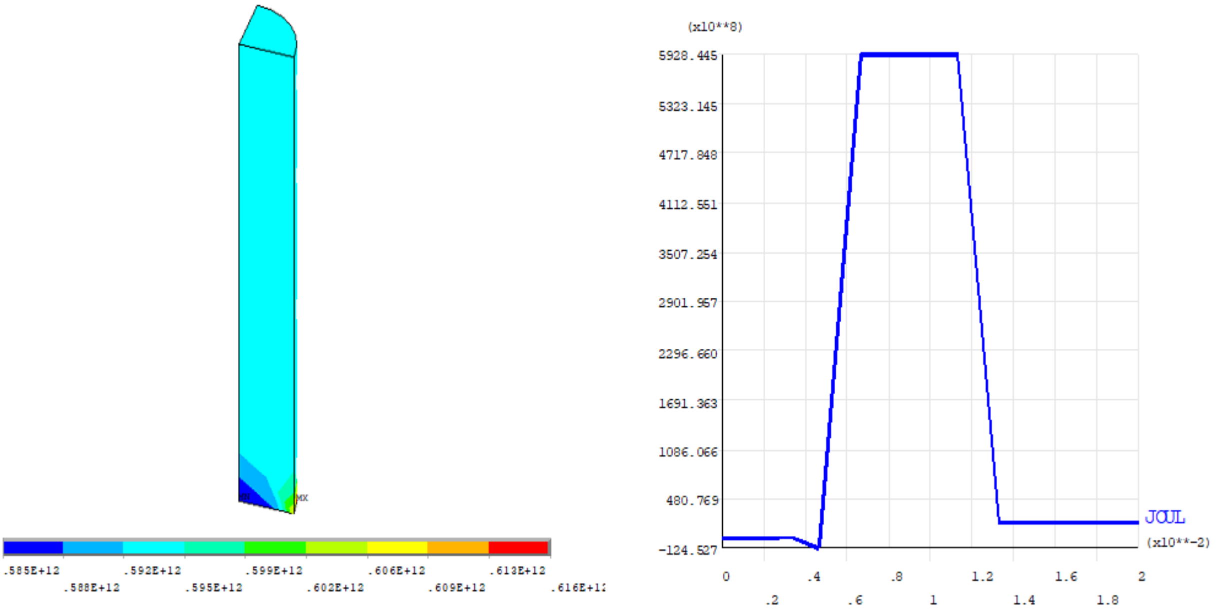

Figure 4. Distribution of calorific value in the electric arc column. T=25000^{0}K

3. CONCLUSION

In general, in a thermal analysis, the specific calorific value can be used as a load (input quantity), from the areas where transformations of some forms of energy into internal energy take place, or imposed values of temperature in certain areas of the considered field.

In the present paper the first variant was used, and therefore the specific calorific value from the electrically conductive areas is used as a load, but especially from the column of the electric arc.

Because this is obtained from the analysis of electrical conduction, in essence any thermal analysis is a coupled analysis.

In a coupled analysis several processes are studied, which in principle, can be from any field of physics.

For the applications frequently used in the industrial practice, processes of nature intervene: electrical, magnetic, thermal, mechanical (structural).

For each process, one analysis is defined, and certain output quantities (results) of one analysis are transferred as input quantities (tasks) for another analysis.

REFERENCES

[1] Cîndea L, Hațiegan C. Modelarea și simularea sistemelor mecanice, Editura EUROSTAMPA, Timișoara, 2021.

[2] Marta C., Doroftei I., Suciu L., Tatucu I, Prisacaru G., Hamat C., Influence of thermal field in the GMAW process: modelling and comparison with experimental results, Annals of DAAAM for 2008& Proceedings of the 19th International DAAAM Symposium, Viena-Austria, , ISBN 978-3-901509-68-1, ISSN 1726-9679.

[3] Cîndea L., Iancu V., Applying the simplex method to optimize welding processes of welded constructions, Analele Universității ,,Eftimie Murgu,, Reșița, 2019, pp.45-48.

[4] I Tatucu, L Suciu, Numerical model for the study of electromagnetic processes in non-stationary regime, Eftimie Murgu University Resita Annals, 2006.

[5] C Haţiegan, N Gillich, C Popescu, E Răduca, L Cîndea, M F Predus and I M Terfăloagă, Study regarding the influence of environmental temperature and irradiation conditions on the performance of a photovoltaic solar module, IOP Conference Science. Material Science and Engineering, Hunedoara, 2018.

[6] Oil & Gas Journal, pp 62 – 65, 2003, Vol 101, No 5.

[7] Weman, K., Welding process handbook, CRC Press, Woodhead Publishing Limited, Cambridge, England, 2003, p. 193.

[8] Cîndea L., Haţiegan C., Pop N., Negrea R., Răduca E., Gillich G-R.,, Moşteanu D., Nedeloni M-D., The influence of thermal field in the electric arc welding of X60 carbon steel components in the CO_2 environment, Applied Thermal Journal Engineering, Vol.103, 2016., p.1164-1175.

[9] Sachajdak A., Sloma J., Szczygiel I., Thermal model of the Gas Metal Arc Welding harfacing process, Applied Thermal engineering, 2018, Vol. 141, p.378-385.

[10] Iancu V., Cîndea L., About the Forces and Moments that influence the Behavior of a Friction Pendulum, Acoustic and Vibration of Mechanical Structures – AVMS, 2020, Vol. 251, p.515-522.

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