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Some considerations regarding the thermal field at welded joints

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Abstract. Mathematical modelling and finite element analysis of the thermal processes, welding of complex metals in terms of chemical composition and structure, allowed to investigate and deepen the heat transfer phenomena and the establishment of a new technological variant of welding. The thermal field, in welding, is depending on the three modes of heat transfer: conductive, convective, manifested by heat losses in the atmosphere and the movement of the fluid in the molten metal bath and by radiation. For the connection of different materials thermo-physical it is proposed that the welding is achieved by moving the thermal source, along the joint, closer to the material characterized by higher thermal conductivity values. The mathematical model and finite element method solution is a modern and modern solution for the optimization of welding technologies, correlating the power developed by the electric arc and the welding speed, so that the final results are as close as possible to the temperature values and dimensions of the welding bath default.

1. Introduction
The quality of the welding joints and the productivity of the processes used are directly influenced by the thermal processes that occur during the corresponding welding operations. The thermal field of welding is dependent on the three thermal transfer modes: conductive, convective (manifested by atmospheric heat loss and fluid movement in the molten metal bath) and radiation. The distribution of temperatures in welded joints is influenced by the linear energy of the thermal source, the thermal properties of the base material (heat specific heat conductivity, material density, thermal diffusivity) and heat losses to the environment.

The thermal field influences phase transformations during welding and therefore the microstructure and mechanical properties of the welded joint. It is also responsible for the occurrence of residual stresses and deformations in welded joints. In the welding processes of the thermal field and its variation over time depend on many factors, but by accepting some simplifying hypotheses, computational relations can be obtained for different practical situations. Simplifying hypotheses are primarily related to the homogeneity and isotropy of the bodies. In addition, the bodies that are welded are infinite or semi-finite as the plates, bars, and massive bodies, respectively. Instantaneous or permanent thermal, fixed or mobile thermal influences by their form - point, linear, plane - the distribution of temperatures in the welded components.

Mechanical and metallurgical changes occurring in adjacent welding bath areas are directly influenced by the thermal processes that occur during welding. The prediction of the temperature field in the welded joints by the finite element method is a quick tool for verifying the welding technology
and estimating the extension of the thermomechanical influence zone. Applying the finite element method involves the meshing approximation of the scope of analysis in order to determine the values of the primary unknowns and sometimes the unknowns. In heat transfer issues, primary unknowns are nodal temperatures, and secondary unknowns are temperature gradients.

Knowing the distribution of temperatures and cooling rates is essential for determining structural changes, volume changes, and hence the properties and load-bearing capacity of welded structures. The stages of the solution, with the finite elements of the thermal transfer problems, are presented schematically in the figure 1.

![Figure 1. Steps of solving thermal transfer problems using the finite element method.](image)

2. Description of the method
The WELD-3D module in SmartWeld is an application that generates optimal welding regimes, taking into account the three-dimensional (3D) heat flow. Specify the size of the required welding bath and WELD-3D calculates all power and speed combinations (welding modes) for optimal welding technology. The model is based on the hypothesis that the thermal source is a moving point that complies with the equation of the conductive heat flux (according to Rosenthal's theory). It is applicable to any melt welding process in which the heat source moves. Melting of metals in the welding area by welding MIG, MAG, TIG welding, plasma arc welding, oxyacetylene welding and laser welding.

The WELD.3D software module allows optimum welding modes to be specified at the user-defined penetration depth of the weld, as well as the shape of welding and the welding pattern on the two-dimensional contour areas.

It is possible to determine the effect of welding parameters on welding area dimensions. Welding area characteristics are function of process variables, output power (q) and partial travel speed (V). The
main part of the program allows obtaining a heat transfer model that calculates process variables (PVs) according to WP parameters. These variables are:

- Melting efficiency - The ratio of the heat required to melt the fusion zone and the net heat input to the area (MeltE) (figure 2, 3)
- Welding width (millimeters) - calculated from the parabolic surface of the weld cross-section (W) (figure 4)
- Depth of welding penetration (millimeters) - Seam depth (P)
- Sensitivity: change in depth relative to power (dP / dq - microns / watt).

Minimizing melt efficiency leads to a welding regime that minimizes the heat required for welding. The purpose of this program is to find welding regimes that can highlight the maximum (or optimal) values of MeltE or the minimum amount of heat input. It also allows the designer to limit the welding depth P, obtaining an area for a hemispherical cross-section.

Figure 2. 2D contours for analysis of 1018 steel welding technology (Melting Efficiency).
Figure 3. 3D surfaces for analysis of 1018 steel welding technology (Melting Efficiency).

Figure 4. 3D surfaces for analysis of 1018 steel welding technology (Width of Weld).
Once a solution has been calculated, the temperature contours in the welding area can be displayed directly in ISO-3D for later analysis. Two types of graphical representations (2-D and 3D surfaces) can be obtained that can improve the analysis of welding technology (figure 5).

As input data are the type of material, the temperature of the base material and the desired welding depth. The completion of the welding procedures results in an updated form of the welding area shape and the display of process variables in the 2-D and 3-D analysis areas when the penetration depth outline and the midpoint of the contour are displayed.

3. Conclusions
The thermal field view, the longitudinal and transverse variations of the temperatures in the welded joints, as well as the temperature values recorded at different nodes (points) located in the area of the welding bath and in adjacent areas lead to the following conclusions:

- Higher thermal conductivity increases the expansion of the thermal influence zone, confirming the results obtained in the case of finite element modelling of the heat transfer in welded joints. The higher thermal conductivity values, the greater the thermal expansion area;
- Higher thermal conductivity requires greater linear energies to be used in welding processes to compensate for rapid heat dissipation through conduction, heat loss through convection and radiation. The higher the thermal conductivity values, the more the welding source needs to be more concentrated, the power of the thermal source, or the heat developed by the electric arc, must be higher;
- The proximity of the electric arc to the metal characterized by higher conductivity values has the effect of: increasing its participation in stitching, a slight expansion of HAZ in this material, and reducing the width of the heat-affected area into a metal characterized by lower values of thermal conductivity;
- Technological welding option is an important advantage in reducing the thermal effects and negative phenomena resulting from them in the metal which more difficultly dissipates the heat developed by the electric arc and is more sensitive to the action of the welding process.
• The mathematical model and the application of the finite element method to solve it is a modern and modern solution for the optimization of welding technologies, correlating the power developed by the electric arc and the welding speed so that the final results are as close as possible to the temperature values and dimensions of the predetermined welding bath.

4. References

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