Mathematical modeling of thermic welding process

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Abstract. A mathematical description of physical processes in a process of thermic welding, allow to conduct computing experiment instead of full-scale experiment. During a computing experiment, without significant material expenditures and in shorter time, a greater number of welding modes can be considered and the most optimal one can be selected. There are software products that allow to conduct computing experiment of different modes of thermic welding. The most interesting are those that allow to independently expand a database of materials, heat sources and various types of pre-processing of welded elements. In the presented paper methods of a mathematical description of thermic welding are discussed. Realized mathematical models in software application packages are presented.

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Introduction

A process of welding is conducted in three stages. That fact is related with that a process of welding can be attributed to a class of so-called topochemical reactions. That kind of reactions in microzones has two stage process of a creation of strong bonds between atoms of connected substances (fig.1). In macrovolumes a process of welding has also a third stage – diffusion [1, 2].

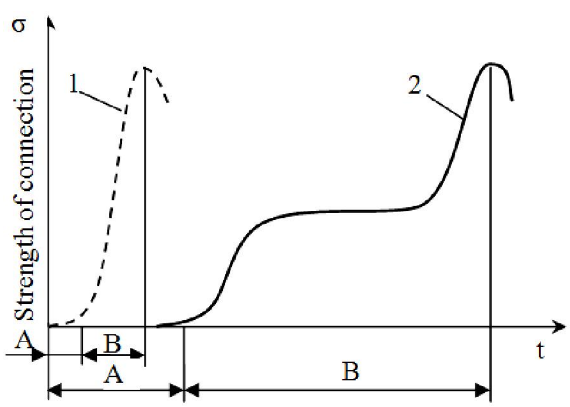

Fig.1. Kinetics of changes in connection's strength σ with fast (1) and slow (2) development of a physical contact (A) and chemical interaction (B) depending on welding duration t.

In the first stage A a physical contact is developed, i.e. a convergence of connected substances on a distances, which are required for an interatomic interaction, also a preparation of the surfaces for an interaction takes place. At the second stage B, which is a stage of chemical interaction, a process of a formation of strong connection in a microzone is finished.

Diffusion processes develop almost simultaneously with intergrowth of dislocations with a plastic deformation of contacting surfaces or with high temperature.

For a qualitative connection of elements it is necessary to ensure a contact for the most part of the connected surfaces and their activation.

An activation of surfaces comprises an imposition of certain energy to surface atoms of solid body, which is required for a breakage of bonds between atoms of a body and atoms of environment, which saturate their available bonds; for an improvement of energy of surface atoms to a level of energy barrier of seizure, i.e. for their transfer into an active state [3, 4].

Main part

Modernization of contemporary technology of welding production for a manufacture of more effective, less material intensive and more reliable welded structures is related with an implementation of new high-strength materials, concentrated energy sources, flexible production systems and growing requirements for a welded joint formation and quality of welded joints. At the same time, welding production engineer should be able to deal with the major technological challenge – be able to select an optimal method and mode of welding for a specified connection and geometric position of welded joint, and optimization criteria are a formation of a welded joint, metal weldability and stability of quality with a consideration of physical and techno-economic restrictions.

A development of mathematical model of welding processes is very labor-intensive and requires a high level of qualification. However, that work economically reasonable, because that model is created only once and then it can be refined, when new physical phenomena in that type of welding are being discovered.

The main physical processes during welding are thermal, diffusion, deformation, electrical, and gas hydrodynamic phenomena. Most of them can be described by means of mathematical physics by differential equations of hyperbolic, parabolic and elliptic type. The mathematical formulation includes a selection of parameters that characterize physical process, for an appropriate differential equation and boundary conditions' description [5, 6].

It must be understood that differential equations only reflect mechanisms of phenomena and completely abstract from conditions of simulated process. To address the specific tasks, such equations must be supplemented by so-called single-valuedness conditions, which determine physical properties of a discussed object and its environment, geometrical dimensions of simulation zone, conditions of an interaction of an object's boundary surfaces with environment and an initial condition of an object's system, which is environment. A combined solution of differential equations with single-valuedness equations ensures uniqueness of a solution for each specific process [6-8].

There are dozens of commercial software systems, including specialized for welding and other technological tasks [9, 10].

Quality and speed of computation are largely determined by a choice of software. SYSWELD is worse of paying a special attention, since this is a unique software product specifically designed for simulation of welding processes of different types.

SYSWELD software [9] was developed in 1970s in the Ministry of atomic energy in France, and then it was transferred for a commercialization to French company FRAMASOFT S.A., a unit of FRAMATOME, which is a well-known developer of technologies used in nuclear energy.

SYSWELD has several modules:

- Welding Wizard — simulates all of the physical processes that occur during welding process;
- Heat Wizard — simulates all of the physical processes that occur during thermal treatment;
- Sysweld Assembly — assembly module that is used for a simulation of an assembly and welding of large structures. It operates values which were transferred from previous modules (fields of stresses and deformations) to create a single mode of deformation throughout a structure.

The software allows to conduct a simulation manually, on a template proposed by the software or automatically. The results can be represented in a form of graphs, charts, numeric values. Software allows to:

- estimate residual deformation;
- minimize residual stresses;
- take into account an influence of a material's geometry;
- optimize welding process;
- assess phase transformations;
- analyze an influence of an active source of heat.

A source of heat is simulated depending on a value of volumetric density of energy $Q_r, (W/mm^3)$, which is applied to elements, located on a trajectory of a source's movement.

SYSWELD developers offer three pre-created forms of heat sources:

- Double ellipsoid;
- 3D conical Gaussian;
- 2D Gaussian.

Volumetric heat source, which is specified by double ellipsoid, is designated for a simulation of welding processes with adding material: MIG, TIG welding, submerged arc welding.

Shape and motion capabilities of the source are presented in fig.2.

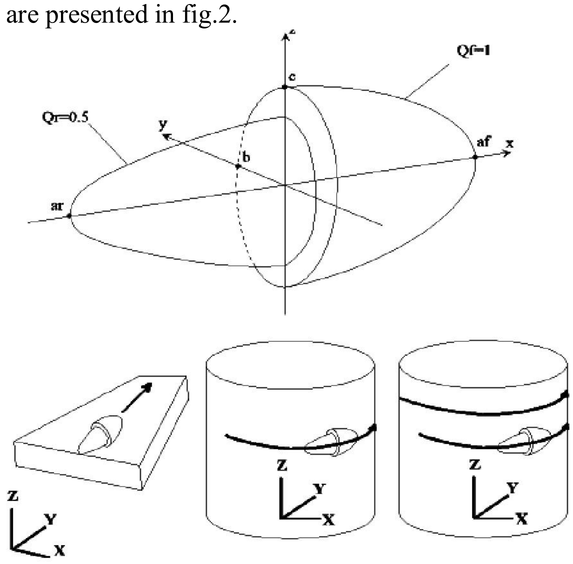

Fig.2. Shape and motion capabilities of the source

According to fig.2 it is possible to simulate forward, rotary and spiral motion of the source.

Fig.3 shows main parameters of the source.

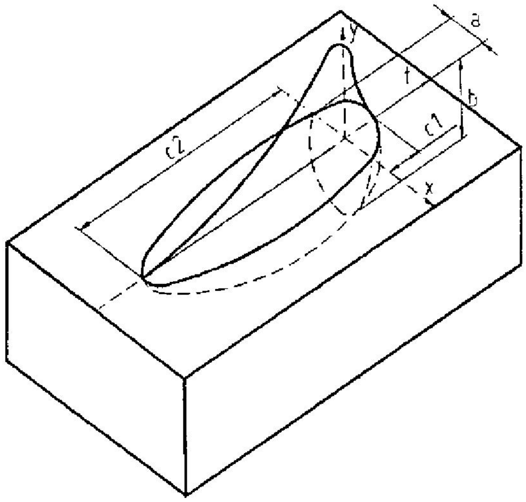

Fig.3. Geometrical parameters of the simulated heat source

Equations that describe the source of heat (fig.2) through its geometrical parameters:

$$Q(x,y,z) = Q_f \exp\left(-\left(\frac{x^2}{a_f^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2}\right)\right)$$

$$Q(x,y,z) = Q_r \exp\left(-\left(\frac{x^2}{a_r^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2}\right)\right)$$

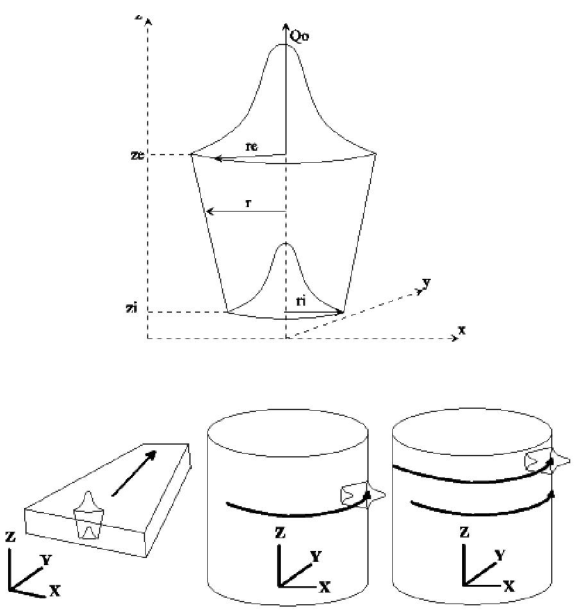

Fig.4. Geometrical shape and parameters of conical heat source

A conical source is designed for a simulation of welding processes with big energy: laser, electron beam. Simulated methods of movement of that source, as well as a following one, re the same as in a case of a volumetric heat source, which is specified by double ellipsoid.

Geometrical shape and parameters of conical heat source are presented in fig.4.

Equations that describe the source of heat (fig.4) through its geometrical parameters:

$$Q(x,y,z) = Q_0 \exp\left(-\frac{x^2+y^2}{r_0^2(z)}\right),$$

$$r_0(z) = r_e + \frac{r_i - r_e}{z_i - z_e}(z - z_e).$$

Gaussien surface heat source is especially well suited for a simulation of a surface treatment, for example, laser strengthening.

A description of the source is presneted in fig.5.

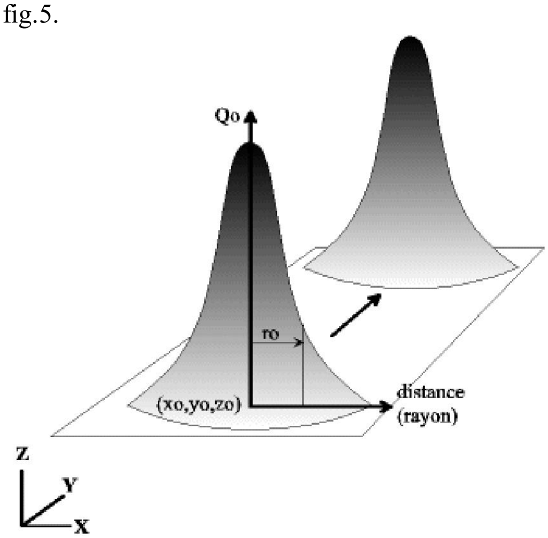

Fig.5. Description of the surface heat source

A description the source of heat (fig.5) through its geometrical parameters:

$$Q(x,y,z) = Q_0 \exp\left(-\frac{x^2+y^2}{r_0^2}\right).$$

Using programming language FORTRAN, user can create any required heat source [9].

The results of SYSWELD application are:

- reduction of production cost;
- optimization of a product's design;
- maximum product safety at an early stage of desgin;

- identification of all of the factors leading to a change in shape, size and features of a product.

Conclusions

Mathematical modeling of processes, which take place in metal during welding, allows to predict the results, and, consequently, select an optimal welding method in advance in order to obtain a welded joint of maximum strength.

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