MAGSIM AND SPOTSIM - SIMULATION OF GMA- AND SPOT WELDING FOR TRAINING AND INDUSTRIAL APPLICATION

by Ulrich Dilthey[1]*, Oleg Mokrov[1], Wladislaw Sudnik[2] and Roman Kudinov[2]

[1]ISF-Welding Institute, RWTH Aachen University,
Pontstrasse 49, D-52062 Aachen, Germany, office@isf.rwth-aachen.de
[2]ComHighTech Institute, Tula University,
Lenin Avenue 92, RU-300600 Tula, Russia, sudnik@oitsp.tsu.tula.ru

ABSTRACT

Simulation systems allow a close inspection of the relation between welding parameters and the resulting weld seam. These systems are very useful in education of weld staff as well as production and planning. In training the influence of variations of parameters can be investigated without the need for real welding experiments. In the design phase requirements of the welding process can be taken into account without several iteration cycles. By estimating a good parameter set for the given welding task the set up phase for a new production cycle can be reduced.

KEYWORDS

MAG welding, spot welding, simulation, weld bead shape, prognosis, temperature field

1. Introduction

The determination of optimal welding parameters is still a difficult task for both spot welding and GMA welding. Based on experimental data and a statistical analysis the result of the welding process can be estimated quite well. This approach works only in determined valid boundaries and doesn't consider important details like contact-tube distance, length of hose assembly, characteristic of power source, dimensions of the gap, and so on. Another cause for the non-exact reproducibility of such predictions is the neglected influences of the chosen measuring methods, e.g. the location of voltage measuring points.

A simulation of the weld formation under consideration of all influences would considerably diminish the efforts for the determination of suitable process parameters. Non-experts would also be able to produce solutions for specific welding tasks by means of a computer dialogue. By variations of welding parameters the relations between welding parameters and the result can be investigated. In addition based on simulation systems the knowledge of the physical and chemical processes in the welding process can be extended and verified.

To achieve a detailed description of the weld formation, which is also in accordance to the process mechanisms, extensive mathematical models are necessary, which, however, can only be solved by numerical methods.

2. MAGSIM

The computer program MAGSIM stands for a fast weld shape simulation and result classification according to the European Standard 25817. It is designed for running on standard personal computers using Windows operating system. Having been originally designed for the simulation of GMA welding processes, the application possibilities of the meanwhile extended program are now, as well, comprising the simulation of pulsed-arc processes, fillet welds, additional mixed gases with O_2 components and high-alloy steels. Based on a mathematical model [1, 2] and a simulation software [3, 4], MAGSIM simulates the physical processes of electric welding circuit and arc as well as the formation of temperature field and bead surface. The particular algorithms which are based upon physical laws, numerical mathematics and verification adjustment allow the analysis of real welding processes regarding up to 50 parameter values, the optimisation of welding parameters for given tasks and the diagnosis of butt joint welding processes [5, 6]. MAGSIM allows, moreover, the calculation of the arc efficiency and the part of drop heat regarding all pulse parameters including current leading and trailing edge. The model is self-consistent so that no additional assumptions (e.g. the efficiency of the arc) are necessary. Aside of the estimation of the weld shape it can be used for the optimisation of the welding parameter. The simulation results of the model have been verified by a comparison with a large number of real welding experiments covering GMA pulsed and non-pulsed welding of fillet and butt joints. The simulation results have an exactness of better than 85 % within a wide range of parameter modifications.
In Figure 1 a screenshot of a 3D-visualisation of the simulation result for a lap joint weld is shown.

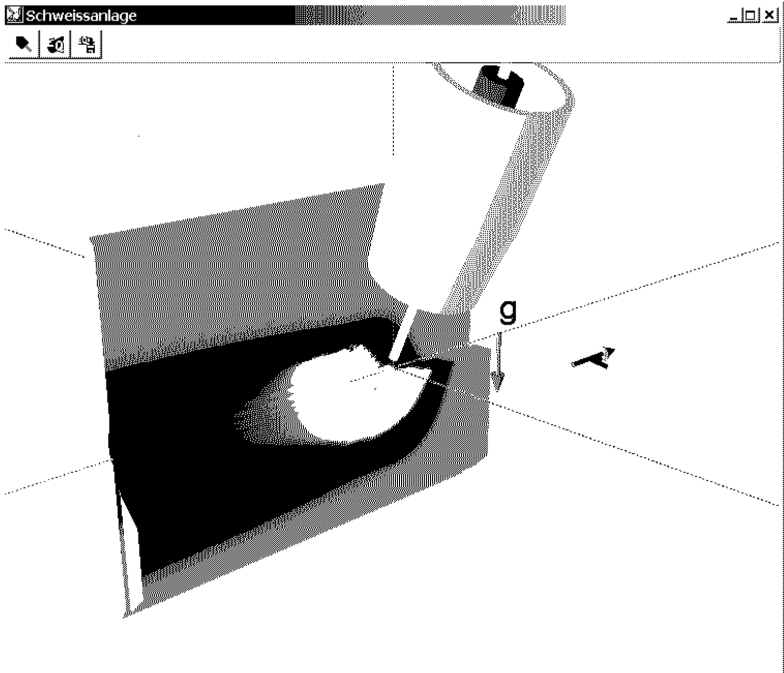


Fig. 1 Screenshot of the 3D-visualisation of the simulation result

2.1 Simulation of the GMA as well as the pulsed-arc welding process

Three combined processes mainly influence the formation of the weld shape:

- Heat generation within the arc area with melting electrode,
- Heat expansion within the welded work pieces,
- Deformation of the weld pool surface.

Each of the above mentioned single processes is analysed sufficient and completely described mathematically. However the construction of complete physical-mathematical models describing the welding processes and their numerical realisation is very complex already for plain joint geometry like butt joints. It is about the necessity of solving the very non-linear coupled three-dimensional temperature problem at the uncovered surface.

2.2 Physical-mathematical model of the process for fillet welds

The wide propagation of the welding of fillet welds (T and overlap joint) required the expansion of the base model and the simulation software. The model description and there simulation are made more difficult for the welding of fillet welds by serious interrelationships:

- The UI diagram of the arc required for the model differs near the inner edge of the groove from that used for the butt joint model,
- the efficiency of the arc is actually higher for the fillet weld model, because the surfaces of the groove sides are heated more by the radiation of the arc stream,
- the share of the molten base metal within the seam is more than 50 %. This fact requires a more precise description of the superficial heat source of the arc with melting electrode,
- a widespread hypothesis about the normal circular power density distribution of the arc has to be extended to a hypothesis of a normal elliptical distribution,
- the existence of a gap - even a gap width of zero - effects a dissymmetry of the temperature field relative to the heat source axis and excludes the calculation of only one symmetric half of the welding zone,
- the melting pool when welding T and overlap joints in horizontal position is not symmetric to the gravity vector. Therefore its components have been taken into consideration for the differential equation describing the melting pool surface,
- The modelling of the pulsed spray arc with frequencies above 100 Hz requires a more accurate description of the electrode drop force.

The general physical-mathematical model can be divided into four partial models:

- work piece

- heat source for pulsed and non-pulsed welding
- temperature field within the work pieces to be welded
- deformation of the weld pool surface

The partial model of the work piece describes parameters of the base material like the enthalpy etc. Experiences with the numerical modelling of arc welding processes have shown that for the correct consideration of the phase transition heat at melting and crystallisation it is better to the use the equation for the energy transmission instead of the temperature.

Three heat sources for the welding process have to be distinguished: the power of the anode, which includes the heating of the wire, the cathode zone and the arc stream. The energy of the arc stream is only partially used for the process depending of the depth of the crater. For the pulsed arc process the power of the arc results from the calculation of the integrated average value of the instantaneous arc power over one period t_{per}. The partial model of the pulsed arc allows the calculation of the arc efficiency and the part of drop heat in consideration of all parameters of the pulsed power source including the leading and trailing pulse edges.

The equation of the stationary thermal conduction of the temperature model is described for movements along the x-axis of the medium in Cartesian co-ordinates. The z-axis is identical with the axis of the wire electrode and the y-axis is perpendicular to the xy-plane. The boundary conditions at the outer surface of the joint describe the thermal heat flows of the hot spot q_k and the arc stream $q_{\Delta Qc}$ as well as the thermal radiation flowing off, the heat convection and the vaporisation. The heat flow of the hot spot is described by an elliptical probability curve. The boundary condition for the second surface is given by the loss of energy by radiation and vaporisation.

The melting pool surface is changed in shape by the electromagnetic and gas kinetic arc influence of the falling drops and the gravity that is balanced by the forces of the surface tension. The surface shape is calculated by the equation for the balance of the above-mentioned forces. The front part of the melting pool is identical with the base material. For the rear part of the melting pool the boundary conditions reflect the parallelism of the crystallisation surface of the x-axis. Dimensional position of welded details is taken into account through directing cos angles between a vector of gravity and positive directions of coordinate.

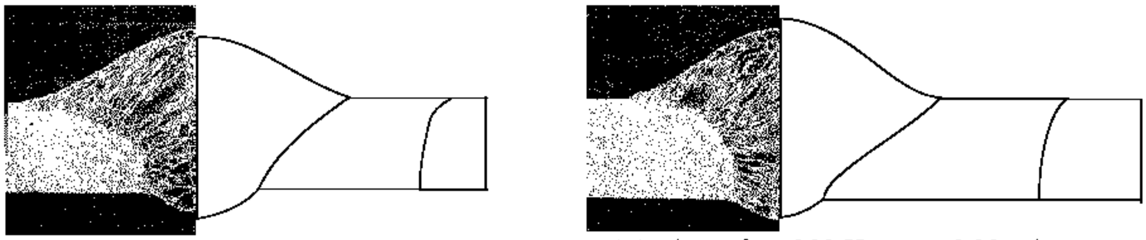
2.3 Realisation

The numerical approximation of the three-dimensional model is done by the finite difference method applied to a regular net with the dimensions 80 x 80 x 100 mm with the mesh width $\Delta x = \Delta y = \Delta z = 0.2$ mm. The widths were adapted additionally for the minimisation of inaccuracies of the stepped approximation. The heat transfer is calculated neglecting the molecular heat transfer along the axis ox. The algorithm of the numerical solution is based upon the use of efficient methods for solving of three-dimensional problems - the local one-dimensional pattern.

After finding the surface $Z_1(x,y)$ the simulation area for the partial model of the temperature field is specified more exact and then the calculation procedure is repeated. For a precise determination of the weld shape 2-3 repetitions are necessary.

Knowing the surface of the molten metal, the co-ordinates of the seam surface can be used as a first approximation for the boundary surface of the simulation zone for the partial model of the temperature field. The selection of the start approximation of the surface mostly allows a solution for the melt surface of the model in one cycle of temperature field calculation.

2.4 Verification of the Simulation Results



v = 7,1 m/min, f_P *= 175 Hz,* v_w *= 1.31 m/min,* *v = 4.4 m/min,* f_P *= 100 Hz,* v_w *= 0.91 m/min*

Fig. 2 Comparison of welding experiment and simulation for pulsed MAG welding, butt weld (thickness 2 mm), D_W = 1.2 mm, Z_K = 15 mm, I_G = 40 A, U_P = 35,5 V, CORGON 18

The important verification of the simulation software was done by the comparison of the calculation results with the polished sections of welding experiments. The extensive verification experiments were done at the ISF-Welding Institute, Aachen University for butt welds and fillet welds with different parameters and seam types. A good correspondence of the simulation results compared to the experimental outcome is obtained for the melting pool parameters and the HAZ area for a T joint, Figure 2 and 3.

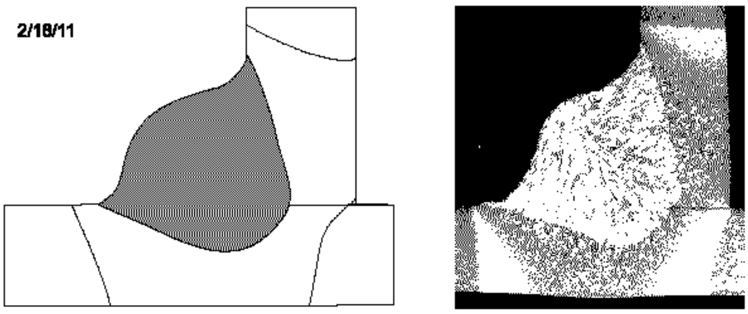


Fig. 3 comparison of welding experiment and its simulation for steel St37-2, fillet weld (thickness 2 + 2 mm), D_W = 1.2 mm, Z_K = 11 mm, torch angle 45°, inclination neutral, v = 0,7 m/min, v_W = 4 m/min (I = 185 A), U = 19 V, CORGON 18

3. SPOTSIM

According to ISO/DIS 14329 [7] the criterions of quality of resistance spot welding are the diameter of the weld nugget, the zone of the heat-influence, the electrode indentation as well as the joint-gap between the sheets. These depend on the welding parameters of the process, which are adjustable on the welding-machine, and the shape of the electrodes. The experimental estimation of quality can be carried out with the help of the computer model of the process. Sudnik and Erofeew [8] developed the coupled numerical model of the process based on the system of differential equations of the mechanical balance of the electrode force and the plastic deformation of the work piece. In the edge conditions of the equation of the electric potential the aktive and the inductive resistances of the welding machine were taken into consideration. During the development of the model [8] Erofeew and Kudinow [9] additionally considered the formation conditions of the gap and the probability of spatter. The programs for resistance spot welding were developed by means of the commercially accessible software ANSYS and SYSWELD.

In the present model the welding current adjustment by phase shift by means of the input of the retardation angle of the control and the ignition of the thyristors. To simulate real conditions database for resistance welding machines and electrode types exist. In order to test the model a series of verification welds of steel sheets with a thickness up to 1,2 mm has been executed. As a result the software SPOTSIM was developed for the IBM PC.

3.1 The databases

The database concerning material contains information about enthalpy, heat conductivity, density, specific resistance and deformation resistance of steels. The properties of the steels can be entered at 6 degrees, which are freely chosen for the temperatures from 20 to approximately 2000°C. The data concerning the alternating current machines contain power, short circuit current, power factor, scope of adjustment of the electrode force as well as the primary no load voltage of the transformators. Information about the standardised electrodes are the measurements of the tip radiuses and the material. These data can easily be completed and edited by the user.

3.2 Calculation algorithm

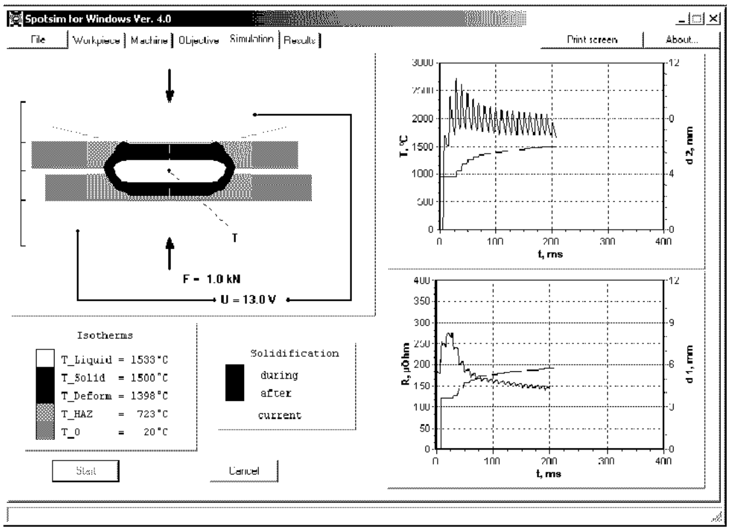


Fig. 4 Simulation of thermal field of a spot weld simulation

After all parameters are chosen from the databases, the starting conditions are calculated. The main cycle of the calculation includes a solution of the two differential equations and a solution of one integral equation for every pace in time.

The edge conditions of the potential equations consider the variations of the sinus voltage between the electrodes. The iterative solution of the potential equation is executed in consideration of the non-linearity of the specific resistance. Concerning the solution of the energy equation for the very small time pace the non-linearity of the temperature-depending heat conductivity can be neglected. The calculation of the plastic deformation with a variable tip radius r_K is continued until the correspondence of the calculated and the adjusted electrode force is reached. The calculation process is repeated for the next time pace.

3.3 Possibilities of the model

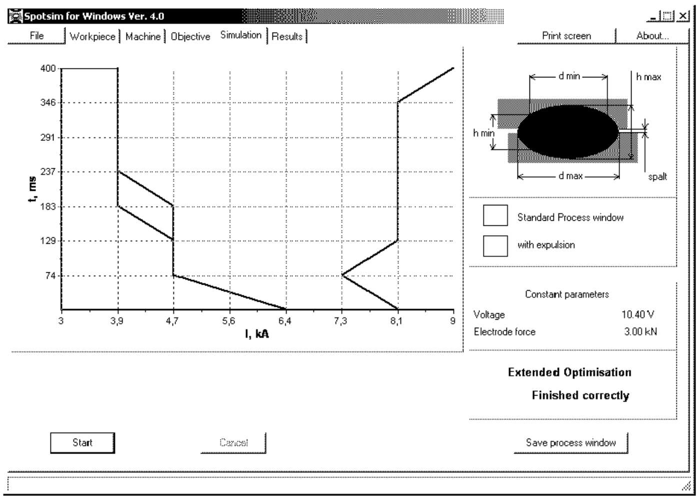


Fig. 5 Welding area in Optimisation

The model calculates the momentary value of the welding current, the weld nugget diameter, the resistance, the temperature (Fig. 4), the sheet gap and the tip diameter between the work pieces depending on the chosen steels, the sheet thickness, the electrode geometry and material geometry as well as the welding parameters. Furthermore the model is able to determine a welding lobe of parameters after determination of the range and limits. That way the user has the possibility to choose appropriate welding parameters depending on the input of the problem.

The analysis function helps to determine the results of a welding with specific welding parameters. Very often the aim of test welding is to determine just the nugget diameter but to find appropriate parameters for a specific geometrical results of a weld. So the input of such a optimisation would be the p. e. minimal nugget size and the results. Fig. 5 shows the results of an optimisation. The large field in the centre represents the area where the required nugget dimensions are fulfilled. The area on the right shoes the parameter where expulsions out of the nugget are possible. The limits of the standard process window can the chosen from 6 different requirements (min/max nugget diameter, min/max nugget height, gap and expulsions). With this welding area he production planer has the opportunity to plan the optimal parameters for his weldings.

3.4 Parameter study and verification

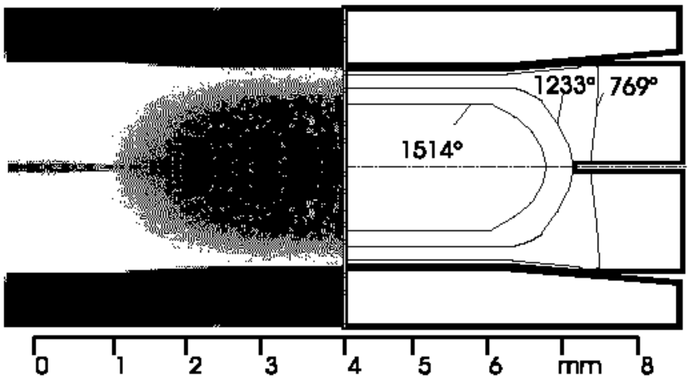


Fig. 6 Comparison of welding nugget in cross-section and simulation,
St12, 1,2 mm, F_{el}=4 kN, U_{LL}=14 V, t_S=18 Per, ϕ=108°

For the validation of the correctness of the calculations a series of experiments is executed. The material chosen for the experiments was St12 with a sheet thickness of 1,2 mm. The experiments were carried out on a alternating current machine of the type Schlatter Selecta P3 with the electrodes G 16X20 (CuCrZr). The welding current was altered between 5 and 10 kA. Electrode forces from 1,5 to 4 kN and welding times from 6 to 18 periods were chosen as further welding parameters. Comparisons between the cross-section of the welded joints and the calculated geometries are exposed in Fig. 6.

4. Hard- and Software Demands

Operating system of the program is MS-Windows and a VGA-graphical interface. The programs, which are programmed with Borland Pascal 7.0 in an object-orientated way, are mouse and menu controlled. Thereby simulation systems allow the direct evaluation of the simulation results and a better understanding by visualisation. The time required for the calculation of one simulation on a PC Pentium with a -frequency of 200 MHz is about 10 seconds.

5. Conclusions

With the support of the data banks SPOTSIM proves to be a device, which eases considerably the engineer practice of production planning in the field of resistance spot welding. By the calculated results the expenses and costs concerning operations scheduling and production can be reduced drastically in comparison to the usual proceedings. The verification has shown that the model simulates sufficiently accurate the welding current, the voltage, the measurements of the weld nugget and the welding zone, the deformation of the working piece surface and the variation of the gap width between the working pieces.

Especially in the field of education and teaching the effects of resistance welding, as there are the formation of the weld nugget during the process of welding, the influence of the welding parameters and of the measurements and types of the electrodes on the geometry of the weld nugget, which can otherwise only difficulty or even not be shown, can with the support of SPOTSIM be demonstrated in a clear and vivid manner.

Therefore the simulation systems are not only recommended for the use in the engineering practice, but also for the education for a better understanding of the quantitative and qualitative proceedings of the process of GMA and resistance spot welding and its optimisation.

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