INFORMATION SYSTEMS FOR SELECTION OF ARC WELDING PROCESS PARAMETERS (Review)

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Existing software programs allowing selection of optimal technological parameters of arc welding of structural steels are considered. Analysis of advantages and drawbacks of the considered software programs in terms of their application by a welding technologist for development of a welding technological process in production was carried out. As to their functional capabilities, the considered software programs belong to different groups of software products. Software «Vertical» with module «System for Calculation of Welding Parameters» belongs to the CAD group. Software programs «Magsim», «System for Computer Analysis of Weldability of Steels», «VirtualARC», «Welding Simulation Suite» and «Simufact Welding» can be regarded as specialised engineering analysis systems for simulation of technological processes. This group of the software products includes commercial general-application software programs for finite element analysis, such as «Abagus», «Ansys», «LS-Dyna», «Catia» etc., which are close to the special systems in their functional capabilities of simulation of the welding and heat treatment technological processes. Purposes of further upgrading of the computer systems developed by the E.O. Paton Electric Welding Institute for selection of consumables for arc welding of structural steels were formulated on the base of analysis of advantages and drawbacks of the best known software products in the field of modelling of the welding technology. 17 Ref., 10 Figures.

Keywords: *software, mathematical modelling, technological process, welding, welding consumables, heat treatment*

The current scientific and technical progress has led to a wide application of computer technologies at a stage of preparation of production. Many special software products allowing virtual reproduction of various technological processes are being developed all over the world.

Reduction of the terms of development and increase of requirements to the quality of fabrication of welded structures resulted in the elaboration of a number of computer programs that facilitate and accelerate the efforts of the welding engineer or welding technologist in design of new welded structures and welding technologies. These software products can be conditionally subdivided into two main groups: systems for computer-aided design of technological processes (CAD TP), which as a rule are integrated with the 3D modelling systems for addressing design problems, and engineering analysis systems for simulation of the welding technological processes.

The E.O. Paton Electric Welding Institute developed the «Arcweldsys» welding software (system for selection of consumables for arc welding of structural steels), which is intended for reduction of the scope of experiments on specimens in selection of welding consumables for a specific welded joint by using the mathematical modelling tools [1]. This article analyses advantages and drawbacks of the best known software products in the field of modelling of the welding technology and formulates the purposes of further upgrading of the computer system developed by the E.O. Paton Electric Welding Institute for selection of consumables for arc welding of structural steels.

The CAD TP group includes software «Vertical» with module «System for Calculation of Welding Parameters» (Figures 1 and 2) developed by the «Ascon» Company (Russia) for integrated automation of the work performed by

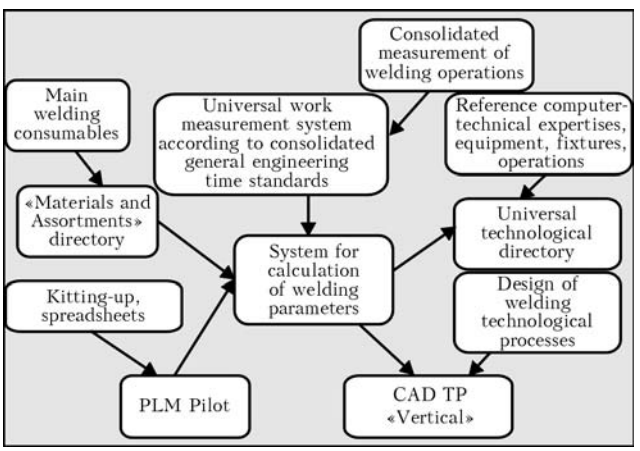

Figure 1. Schematic diagram of module «System for Calculation of Welding Parameters»

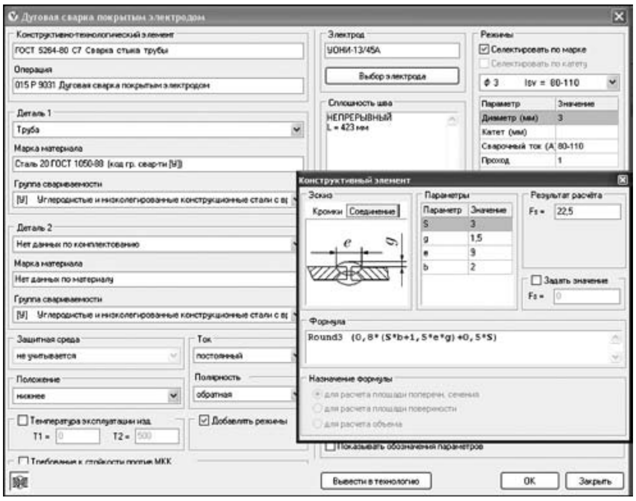

Figure 2. «Vertical» software window

the welding technologist in design of the welding technological processes [2–4]. The earlier installed 3D modelling system «Compass» or other similar system is required for operation of CAD TP «Vertical». The module operates in the CAD structure and solves the following problems: computer-aided selection of parameters for the main welding processes, computer-aided selection and calculation of the rate of consumption of welding consumables, and calculation of consumption of the power and main time for a manufacturing step.

In design of the welding technological processes and selection of the process parameters, the module allows for structural elements of the welds, position of the weld in space, materials used, characteristics of the equipment and other necessary parameters. The method of welding of parts can be specified for the entire weld or separately for each welding pass. The possibility exists of automated selection of welding consumables allowing for the requirements to intercrystalline corrosion and conditions of operation of a welded structure.

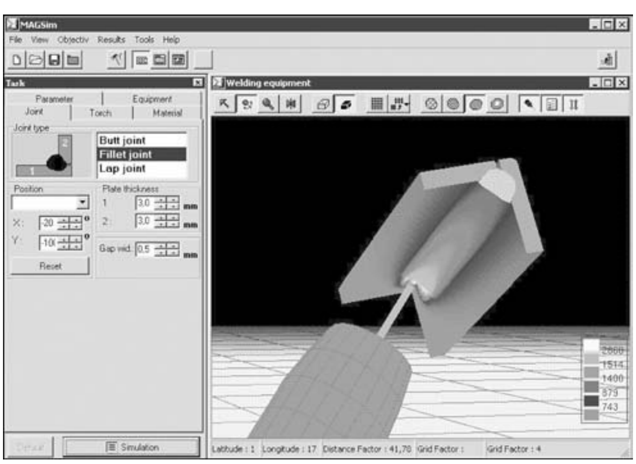

Figure 3. «Magsim» software window

Selection of welding consumables and technological parameters of welding is performed on the basis of the information bank of knowledge that includes corresponding directories «Materials and Assortments» and «Universal Technological Directory» (see Figure 1). In fact, the module is a calculation-information system, which is not intended for modelling of the welding process. Large quantity of service functions that facilitate drawing up of the documents on a welding technological process makes this software very convenient for the welding technologist in production. Drawbacks of software «Vertical» with module «System for Calculation Welding Parameters» include the probability of problems in selection of the welding technological parameters in a case of using new consumables or welding methods, for which the data and knowledge bases have no data, as well as the high labour intensity and cost of application of this system in production related to the need to install the 3D modelling system and CAD TP «Vertical», which also adds to the high cost.

Software «Magsim» (Figure 3) for numeric analysis, diagnostics and parametric optimisation of the gas metal arc welding process was developed as a result of the collaborated investigations conducted by the Tula State University (Russia) and the Aachen Technical University (Germany) [5–7]. Software «Magsim» can be classed with the engineering analysis systems for simulation of the technological processes. This software allows the welding engineer to simulate the effect of the welding process parameters on the quality of formation of a welded joint in order to reduce the quantity of experimental specimens. The software makes it possible to statistically estimate the effect of deviations of the technological parameters during welding on the quality of the weld, as well as automatically define the optimal parameters.

The main drawback of «Magsim» is that the welding simulation results are limited only to the problem of formation of a welded joint, although for development of the welding technology in production, in addition to this information, the welding engineer also needs other technological data, such as mechanical properties of the welded joint, risk of formation of hot and cold cracks, etc.

The highest-capacity specialised system for simulation of the welding and heat treatment technological processes is a package of the software products joined into the «Welding Simulation Suite» rule box [8, 9]. The developer of this system is French Company «ESI Group»,

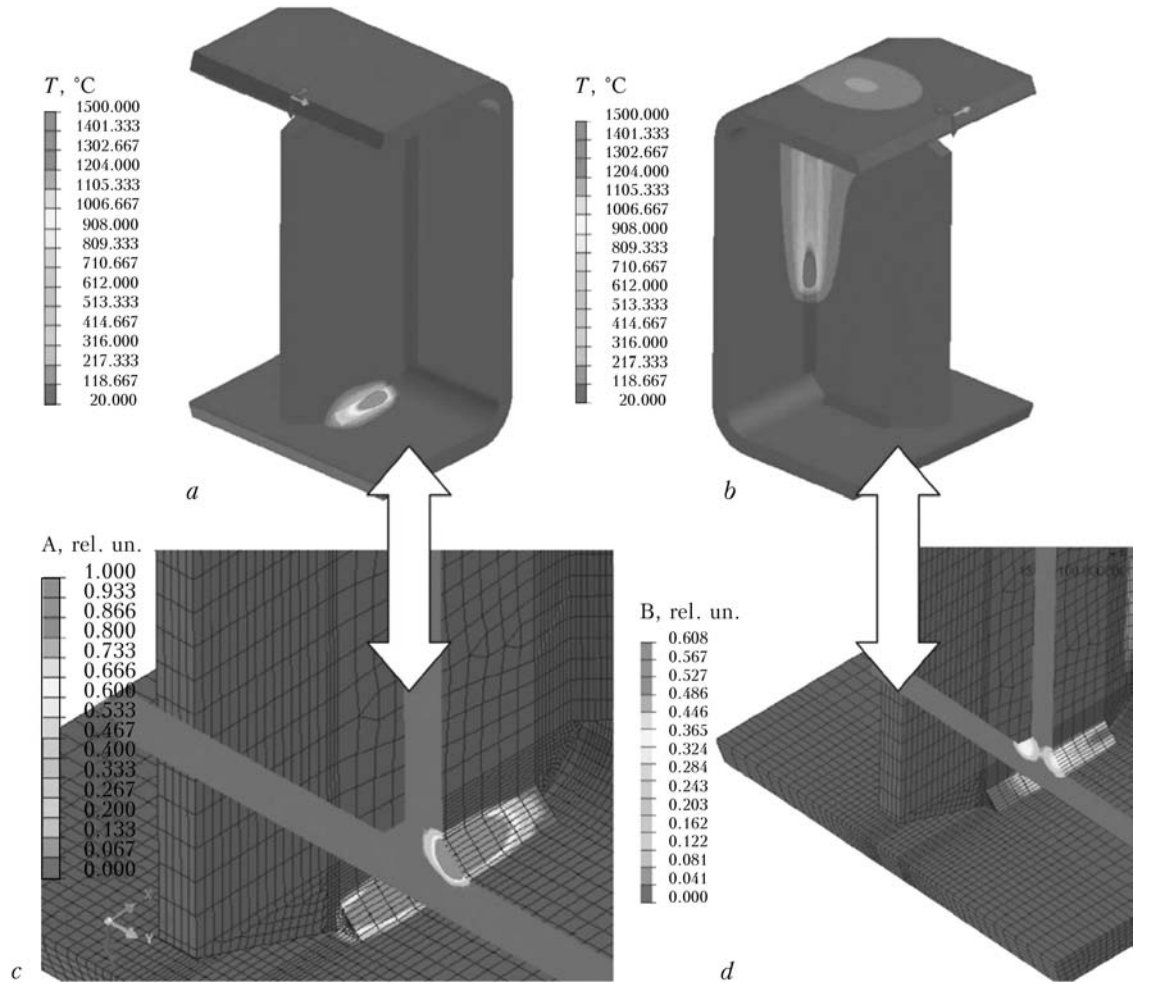

Figure 4. Results obtained with software «Sysweld/Visual-Weld»: *a*, *b* — distribution of thermal fields; *c*, *d* — relative content of austenite (A) and bainite (B) in weld

which is one of the leaders in development of CADs and simulation of the technological processes. The said software package includes:

- software «Sysweld/Visual-Weld» for simulation of the local regions of welded structures;
- software «Weld Planner» for simulation of the process of welding of thin-sheet structures;
- software «Pam-Assembly» for simulation of the processes of assembly-welding of large-size structures of a complex geometry.

Software «Sysweld/Visual-Weld» allows simulating welding and heat treatment processes, temporary and residual stresses and strains in a weldment or welded structure, mechanical characteristics and strength of the materials subjected to technological processing (Figure 4). Simulation of the welding processes includes all types of the welding technologies allowing for mechanical, thermal and metallurgical properties of materials. The models and data bases included into software «Sysweld/Visual-Weld» allow the thermal-metallurgical processes to be analysed for steels and aluminium alloys. The software operates with the thermokinetic diagrams describing the phase transition process (Figure 5).

The software has the possibility of developing a geometric model of a weldment or welded structure built in some CAD environment. Results of the calculations, including on stresses and strains, can be exported for further calculations to other calculation modules developed by the «ESI Group» Company, such as:

- «Systus» for investigation of initiation and propagation of fatigue cracks;
- «Pam-Stamp» for analysis of the process of stamping of welded sheet parts;
- «Pamcrash» for analysis of fractures in welded structures.

Software package «Welding Simulation Suite» is characterised in many cases by excessive capabilities and complexity for the welding engineer in production, requires special knowledge on application of calculation methods and long-time training of a user, and has a high cost.

Module «Simufact Welding» [10] is another specialised system for simulation of the welding processes. It is included into system «Simufact» (Simufact Engineering GmbH, Germany) [11] for general engineering analysis of different technological processes. First of all, this module is

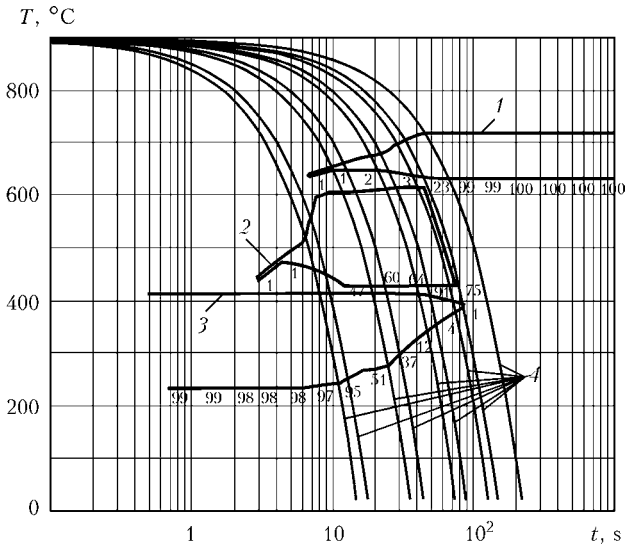

Figure 5. Presentation of thermokinetic diagram in software «Sysweld/Visual-Weld»: *1–4* — phases 1–4, respectively

intended for prediction of welding distortions. Also, it allows evaluating properties of the penetration zone (PZ) and HAZ. The problem-oriented user interface helps the welding engineer to conduct sufficiently complicated simulation of the physical-metallurgical processes occurring during welding. The software is based on a combination of analytical approaches and non-linear numerical simulation. According to the developer's description, the software is characterised by the following functions:

- time-synchronised monitoring of operation of several welding robots;
- prompt calculation of different variants differing in welding parameters;
- prompt change of the welding process parameters (welding sequence and speed, welding heating parameters, and clamping conditions);
- optimisation of sizes and properties of FZ and HAZ, as well as the level of welding stresses and strains.

Advantages of software «Simufact Welding» include sufficiently wide capabilities of simulation of the welding process for prediction of the quality of formation of a welded joint, including the multi-pass one, and evaluation of properties of PZ and HAZ allowing for the transformation structures, as well as temporary and residual welding stresses and strains. Despite using the complicated mathematical models, the software is oriented to an engineering application in production. A distinctive feature of this software is the possibility of optimisation of robotic welding and monitoring of synchronised operation of welding robots in production.

Commercial general-application packages of finite element analysis, such as «Abaqus», «Ansys», «LS-Dyna», «Catia» etc., are close to the specialised systems in functional capabilities of simulation and modelling of the welding and heat treatment technological processes. The latest versions of some of these packages include the specialised calculation modules for simulation of the welding processes [12].

For example, «Abaqus» is not the specialised welding software, but it can be applied for simulation of moving heat sources and analysis of thermal and mechanical processes occurring during welding (Figure 6). Analysis of the thermal processes is carried out by means of the user subprograms [13]:

- «Dflux» is applied for determination of heat transfer in welding in a case of a concentrated heat flux, which moves along the welding line, by simulating movement of a welding heat source;
- «Gapcon» is applied for activation of heat conduction between the base and filler metals, when the welding source passes through a certain element;
- «Film» is applied for activation of heat conduction to simulate the cooling process, when

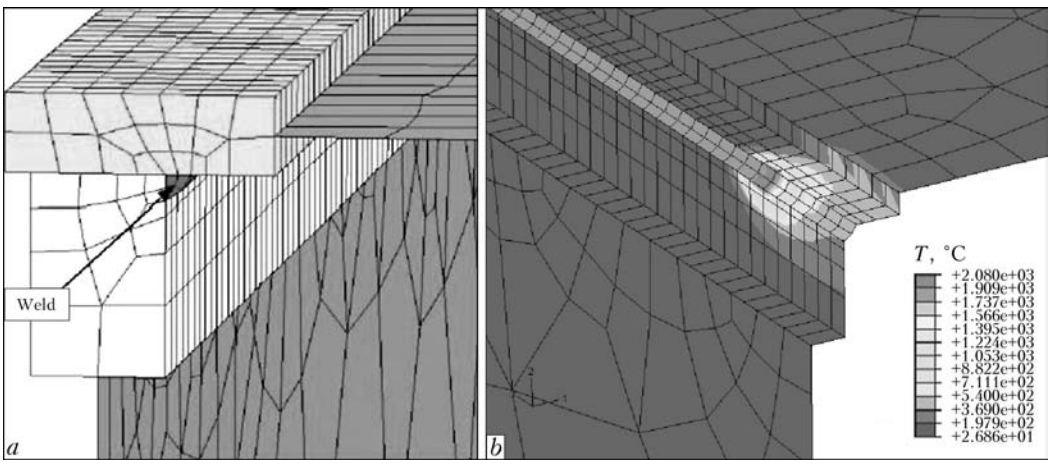

Figure 6. Software «Abaqus»: *a* — finite element model of weldment; *b* — distribution of thermal fields

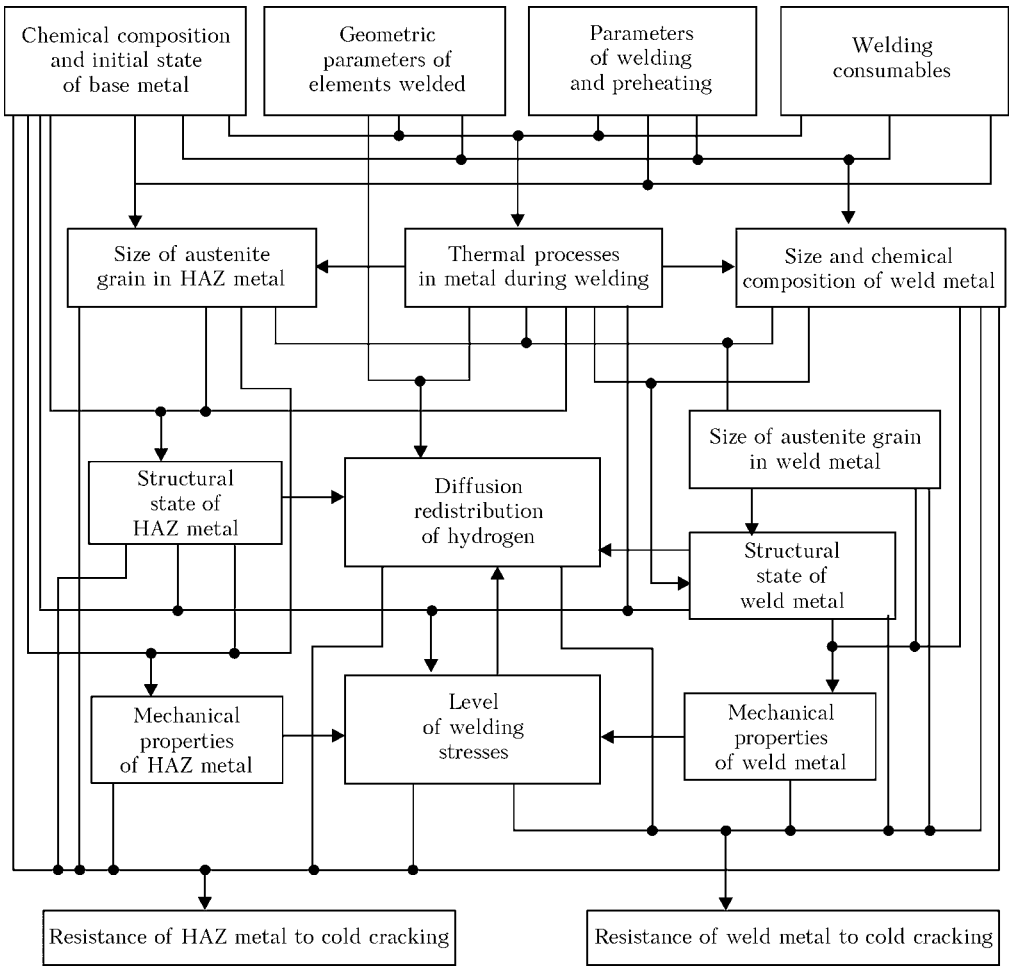

Figure 7. Schematic of interrelations of indicators of weldability of low-alloy steels with the processes occurring in metal during welding in software «System for Computer Analysis of Weldability of Steels»

the welding source passes through a certain element.

The thermal analysis results are used as the source data to solve the mechanical problem, yielding evaluation of welding stresses and strains. To simulate the thermal-metallurgical processes during welding it is necessary to develop in house or buy from a third developer the additional program modules, which allow for structural transformations occurring in steels during the welding temperature cycles. The drawbacks also include high complexity of the program, long-time training to operate it, and high cost. All these factors make software «Abaqus», as well as other commercial general-application finite element analysis software products, of little use for development of a welding technology by the welding engineer in production.

The N.E. Bauman Moscow State Technical University developed the «System for Computer Analysis of Weldability of Steels» (Figure 7) [14, 15], comprising the engineering part for prompt analysis of technological variants of welding of typical joints, which is implemented on the basis of software package «Weldability of Alloyed Steels» [16] and the data base on properties of materials.

Traditionally, selection of a rational variant of consumables for arc welding of modern structural steels involves a large quantity of experiments, in the course of which the comparative results are obtained on a number of parameters: conditions of formation and chemical composition of the weld metal or PZ, microstructure of the PZ and HAZ metals, susceptibility to hot cracking, standard mechanical characteristics (hardness, yield stress, tensile strength, elongation, reduction in area and impact toughness) in different regions of the welded joints, as well as special properties (long-time strength at corresponding temperatures, corrosion resistance, etc.). All this requires appropriate tests of each alternative variant of welding consumables and parameters for a specific base material. Considering a wide range of existing consumables for arc welding of structural steels, the substantiated experimental selection of a rational variant requires either a rich experience or numerous experiments.

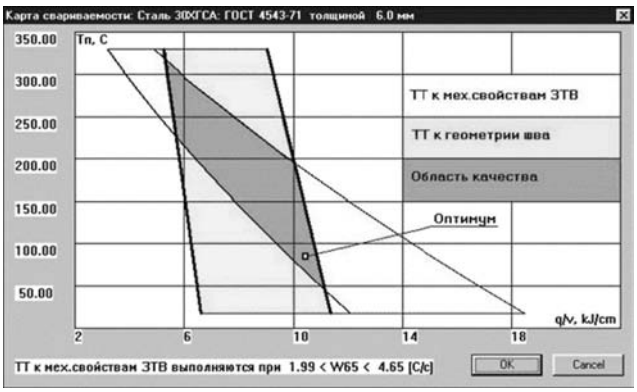

Figure 8. Plotting of the quality region in optimisation of thermal parameters of welding in software «System for Computer Analysis of Weldability of Steels»

Software «System for Computer Analysis of Weldability of Steels» makes it possible to considerably reduce the labour intensity in design of the welding technology and solve the problems of optimisation of technological parameters of the process of multilayer welding of low-alloy steels. Integrated analysis of technological variants of welding is carried out by modelling the set of the physical-metallurgical processes occurring in metal that form the weldability indicators. Optimisation of the thermal conditions of welding is performed to ensure the required combination of properties of the HAZ metal. Parameters of welding and edge preparation of the joints, which provide the preset sizes of the welds, as well as the preheating temperature to achieve the required structural state of the HAZ metal and resistance to cold cracking are determined at this stage of the calculations (Figure 8).

Software «System for Computer Analysis of Weldability of Steels» was developed with a purpose of more understandable modelling of the multilayer welding process for the welding engineer in production.

Software «Virtual ARC» (developer — Company «ABB», Switzerland), which is an efficient tool for selection of the MIG/MAG welding process equipment and parameters, was developed to facilitate adjustment of the robotic welding equipment under conditions of modern high-tech production. The software has a convenient graphical interface, combines 2D modelling, and comprises data of experimental measurements and neuron networks for prediction of formation of the weld in arc welding of low-carbon steels.

The results of modelling of physics of the arc, heat and mass transfer are used as the source data for the neural network to predict quality and size of the welds, as well as probable welding defects. According to the developer's data [17], the key functions of software «Virtual ARC» are as follows:

- planning of the technological process of MIG/MAG welding;
- adjustment of the MIG/MAG welding parameters;
- prediction of the weld shape and penetration;
- prediction of geometric parameters of the weld;
- prediction of geometric defects of welding;
- estimation of the cost of welding;
- formation of technological documents;
- optimisation of productivity and quality of the welding process.

Therefore, the main specialisation of software «Virtual ARC» is selection of the optimal welding equipment and parameters in terms of the quality formation of a welded joint in MIG/MAG welding of low-carbon steels (Figure 9). The drawbacks are that the software does not allow for structure and mechanical properties of the resulting welded joint. The class of low-carbon steels is another limitation of practical application of the software.

Early in the 2000s, the E.O. Paton Electric Welding Institute developed computer system «Arcweldsys» [1], which is intended for reduction of the scope of experiments on specimens in selection of alternative welding consumables for a specific welded joint by using the mathematical modelling tools and corresponding information support. As the source information, the system uses certificate data of a manufacturer of welding consumables concerning variants of the welding consumables recommended for arc welding of a given type of structural steel, arc welding parameters, deposition efficiency, and chemical composition of the deposited metal. These data are entered together with indication of the type of a structural steel welded (base metal) and its chemical composition into the system by a user (Figure 10).

As a result, the system gives the following information on each alternative variant to the user:

- size and shape of PZ for the root weld and subsequent passes (conditions of weld formation, risk of burn-through, etc.);
- chemical composition of the PZ metal;
- microstructural composition of the PZ and HAZ metals;
- mechanical properties (hardness, tensile strength, yield stress, elongation, reduction in area, impact toughness);

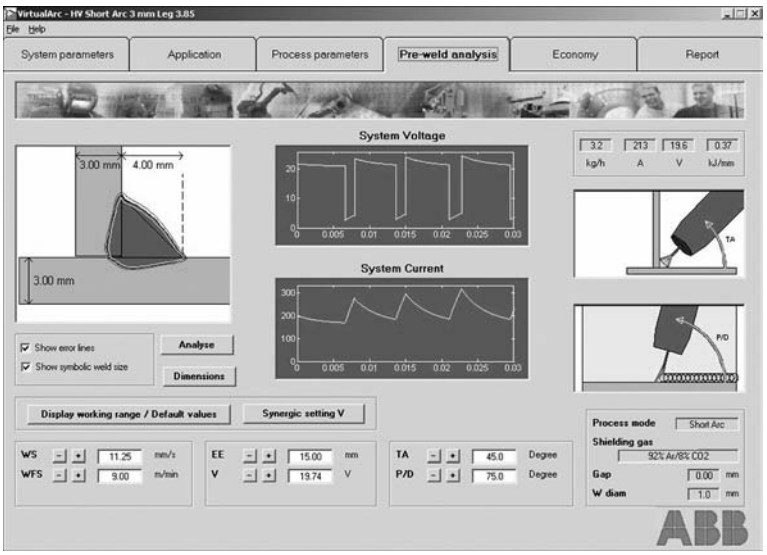

Figure 9. «Virtual ARC» software window

• *KCV* at temperatures of –20 – –70 °C in PZ and HAZ;

• risk of cold and hot cracking.

The following main drawbacks of the system were revealed in the process of its practical application: unsatisfactory accuracy of calculation of temperature fields in a case of welding at a high speed of the heat source due to using the calculation algorithms within the framework of the 2D problems, impossibility of modelling welding for such materials as stainless steel and aluminium and titanium alloys, and inconvenient software interface. At the same time, the system turned out to be rather efficient, found a number of customers in Ukraine, and was applied to perform numerous studies by specialists of the E.O. Paton Electric Welding Institute.

Based on considering advantages and drawbacks of the best known software products in the field of modelling of the welding technology, and as a result of analysis of the efficiency of application of the developed computer system, as well as allowing for the progress in modern computer engineering and calculation methods of mathematical modelling, physical-chemical and metallurgical processes occurring in welding, it was concluded that it would be expedient to further upgrade the existing version of the computer system. Such upgrading is performed on a base of redesign of mathematical models and calculation algorithms on determination of temperature fields (cycles) for different types of the welded joints, including through utilisation of 3D models, widening of the system application field to cover the class of stainless steels by adding new mathematical models and corresponding calculation algorithms on generation of extra information that is important for the welding engineer. This includes, for example, the degree of sensitisation of metal due to the welding cycle in multi-pass welding of stainless steels, updating and replenishment of data bases on properties of the base metal and welding consumables, including entering into the data bank the properties of materials, thermokinetic diagrams in the digital

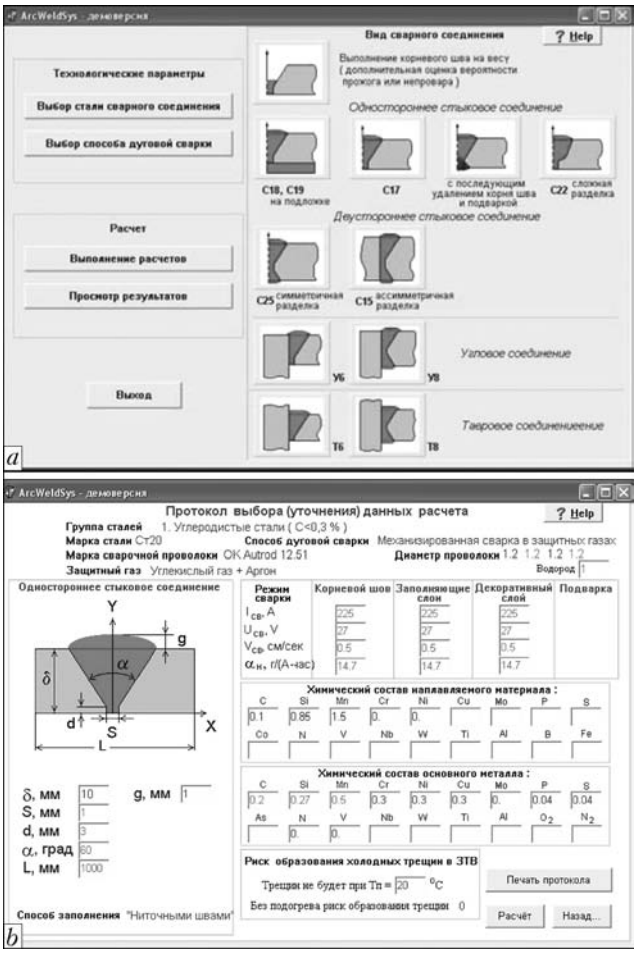

Figure 10. Interface of software «Arcweldsys»: *a* — main window; *b* — protocol of selection of calculation data

form for a more precise description of phase transformations during the thermal welding cycle, development of a more friendly and intuitively understandable user interface of the system with additional service functions for automatic drawing up of the technological documents.

Conclusions

1. Analysis of the software products available in Ukraine and abroad for modelling and simulation of the welding technology showed that now the welding engineer has high-capacity tools for design of welded structures and welding technologies.

2. The E.O. Paton Electric Welding Institute of the NAS of Ukraine developed specialised welding software «Arcweldsys» (system for selection of consumables for arc welding of structural steels), which is intended for reduction of the scope of experiments on specimens in selection of welding consumables for a specific welded joint by using mathematical modelling tools.

3. Comparison of advantages and drawbacks of the best known software products in the field of modelling of the welding technology resulted in the formulation of the purposes of further upgrading of the computer system developed by the E.O. Paton Electric Welding Institute for selection of welding consumables for arc welding of structural steels, which are meant for increasing the accuracy of the obtained prediction results and making it more convenient in operation for the welding engineer.

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Received 10.01.2013