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*weld, gas tungsten arc,*
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# THE COMPUTER SYSTEM FOR DESIGN OF THE TIG WELDING OPERATION

The paper presents a computer system dedicated to simulation of the TIG welding process. The main functionality of the system, i.e. support and facilitation of design of welding technology, will be obtained through flexible combination of the modular architecture of the numerical library and optimization procedures. The TIG heat source model and a structure of a computer system is described. The analysis of phenomena occurring in welded material is important for a selection of optimal process parameters. This contributes to improvement of the product reliability. Particular attention is focused on the development of a reliable numerical model of TIG welding for the linear joint. All process parameters are identified and gathered together in one complex database. The phenomenological heat source model is validated by comparison of evaluated temperatures in a discrete pint with experimental measurements. The validated heat source model is used as the main part of a computer system supporting TIG welding. The architecture of this computer system as well as details of implementation are described in the paper.

## 1. INTRODUCTION

Specialized computer systems supporting work of engineers and technologists became crucial part of business in many industrial companies. This was initiated by the fast development of implementation techniques, as well as access to programming libraries and frameworks. Strong need of applicability of such systems is visible especially in case of companies, which are endangered on fast changes of market and Clients' demands. In the aviation industry these demands are related with the elevated properties of materials and final products. As a response to those requirements, the idea of dedicated computer system for numerical simulation of TIG welding was created. The concept itself is not new, it was presented in [1] as an automated approach to modelling of sophisticated production processes. A decrease of the manufacturing costs is the main aim of that approach. This methodology was further developed and based on object oriented modelling to make it

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flexible and reusable [2]. The system, which is proposed in this paper, is also based on the component and open architecture. These features allow users to implement their own numerical procedures and to apply them during simulations of welding, what would be one of the most important advantages of proposed solution. According to the state-of-the-art, most of the commonly used computer systems are closed for user modifications, allowing performance of simulations with conventional well known numerical models, what considerably hinders the development of welding modelling. The subsequent sections of this paper present details of TIG process, the numerical model with selected results of simulations and the system architecture.

## 2. TUNGSTEN INERT GAS PROCESS

The TIG process, also known as the Gas Tungsten Arc Welding (GTAW) has been commonly used in aerospace industry for last sixty years. In this electrodes are made of pure tungsten or tungsten combined with oxides (thoriumoxide, zincroniumoxide). The welding pool is protected by a shielding gas. Temperature resistant electrode is suitable to create a stable electric plasma beam, called also the electric arc, where temperature ranges between 12000 K and 15000 K. The plasma beam creates a weld pool where temperature ranges between 1700 K and 2500 K. The energy from the arc through the weld pool is conducted to the weld joint. The TIG welding can be realised in three variants respectively to currents: direct current (DC) with a positive electrode, DC with negative electrode or alternative current (AC). The AC is mainly used for the welding of aluminium and magnesium. The DC can be applied for majority of materials, including also thick plates of aluminium. For protection from atmospheric contamination the mentioned shielding gas has to be used. In most cases argon, helium or mixture of both gases creates an expected shield. Argon is applied for unalloyed, low alloyed and stainless steels for thickness less than 3 mm, while helium is more commonly used for thickness larger than 3 mm [3]. Example of TIG welding process is shown in the Fig. 1.

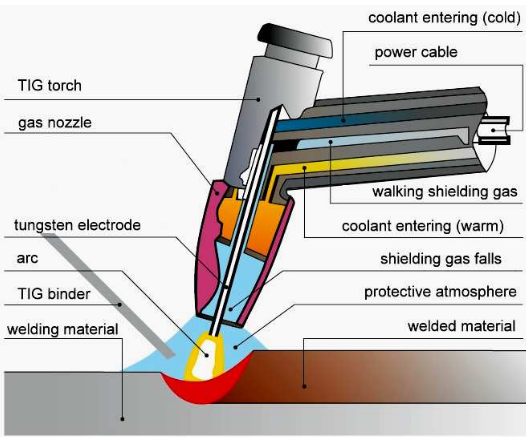


Fig. 1. TIG welding process scheme.

## 3. MODEL OF HEAT SOURCE

Numerical model of heat source in welding is well described in the literature, e.g. in [4],[5]. The approach proposed and validated by the Authors in [5] is used. The main equations of the model are repeated below. The temperature field induced during welding is described by the energy balance equation:

$$\rho C_p \frac{\partial T}{\partial t} = -\nabla \cdot k \nabla T + \dot{Q} \tag{1}$$

where $\rho$ – density of the material, $C_p$ – specific heat, $T$ – temperature, $k$ - conductivity, $t$ – time, $\dot{Q}$ – rate of internal heat generation.

Solution of equation (1) has to fulfil relevant boundary conditions. The welding torch generates heat which is transferred from the source to the rest of the plate by conduction. Afterwards, the material starts to cool down to the ambient temperature, according to the thermal boundary condition including convection and radiation behaviour. The welding involves high temperature and simulations require accounting for radiation as the important part of the heat dissipation:

$$-k\nabla T = \alpha (T - T_a) + \sigma\varepsilon [(T)^4 - T_a^4] \tag{2}$$

where: α –convective heat transfer coefficient, $T$ – local surface temperature, $T_a$ – ambient temperature, $\varepsilon$ - emissivity, $\sigma$ – Stefan-Boltzmann constant.

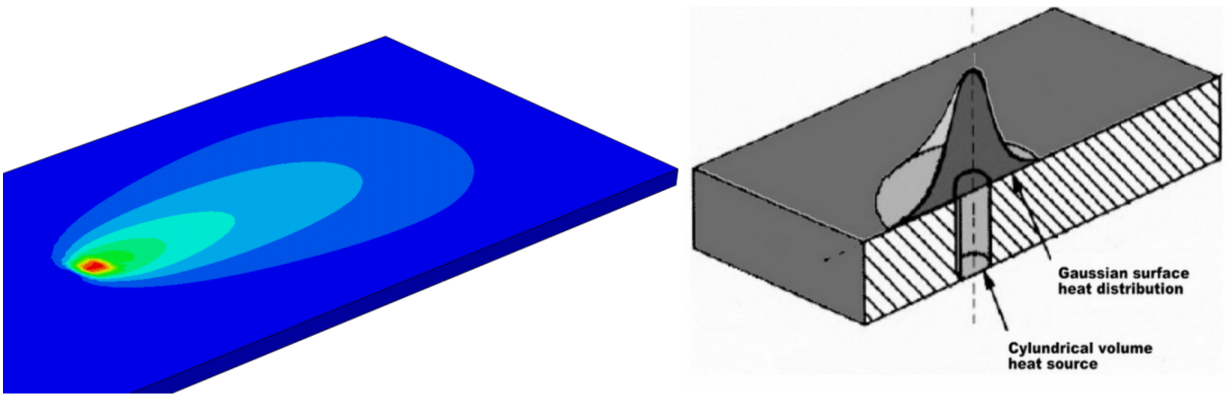


Fig. 2. Temperature distribution produced by a moving heat source (left) and Gaussian-bell distribution of the heat flux (right)

A moving heat source in the TIG welding process is modelled by the motion of the Gaussian-bell shape temperature field which, on the top surface of welding joint, forms a disk-like shape elongated in the welding direction. The Gaussian heat flux distribution is the most popular model of welding heat source [6]:

$$q = \frac{3W}{\pi r^2} \exp\left(\frac{-3x^2}{r^2}\right) \exp\left(\frac{-3y^2}{r^2}\right) \tag{3}$$

where: $W = \eta UI$ – power input, $\eta$ – arc efficiency, $U$ – voltage, $I$ – current, $r$ – heat flux radius, $x$, $y$ – position on a heating surface. The problem with modified Goldak heat source [7] is described in details in [8],[9].

The example of the Gaussian bell heat source model is shown in Fig. 2.

## 4. VALIDATION OF HEAT SOURCE

The modelled TIG welding has been validated for the Inconel alloy and results are shown in in [5]. In the present paper results of validation conducted on the basis of experimental data available in [10] are presented. In these test the 5456 aluminium alloy plates of the size: 3.2×200×250 mm were welded. The properties of the alloy are: density 2700 kg/m$^3$, specific heat 1066 J/kg$^o$C. The heat transfer coefficient of 10 W/m$^2$K and the emissivity of 0.82 are assumed. The process of welding is performed along the welding path, while in the neighbourhood of this path twelve thermocouples are placed to collect signals about temperatures during the process. The locations of these thermocouples are shown in Fig. 3.

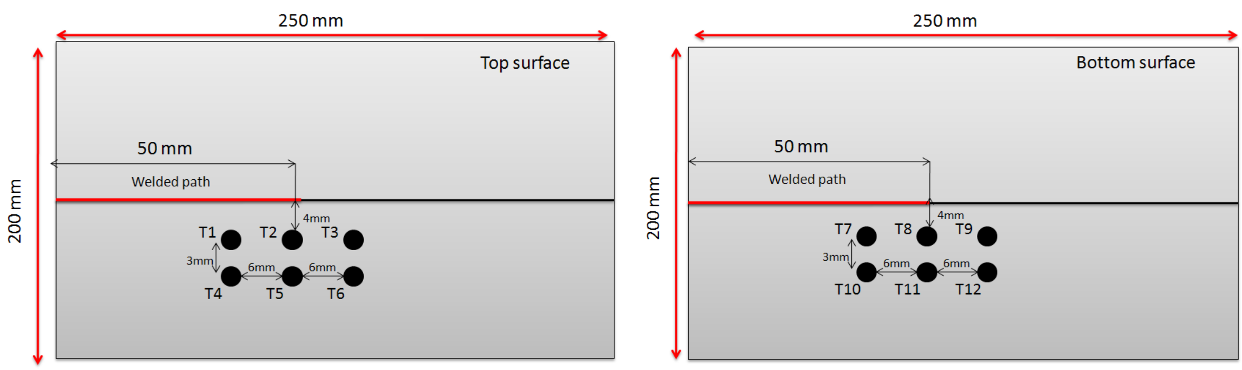


Fig. 3. Locations of thermocouples on the top and bottom surfaces of welded joint

Two experiments with argon shield protection were performed for two different electrode velocities ($U$) and heat source power ($W$): (1) $W$ = 670W, $U$ = 3 mm/s, (2) $W$ = 975 W, $U$ = 7.24 mm/s. The efficiency ($\eta$) varies in these two simulations. In the first case, the efficiency is 0.5, while in the second experiment it is equal 0.78. The comparison of results obtained in numerical simulations and experimental measurements is presented in Fig. 4 and 5. In addition, the plot of differences between measured and calculated temperatures is presented in Fig. 6. It can be noted a good predictive capability of the phenomenological model.

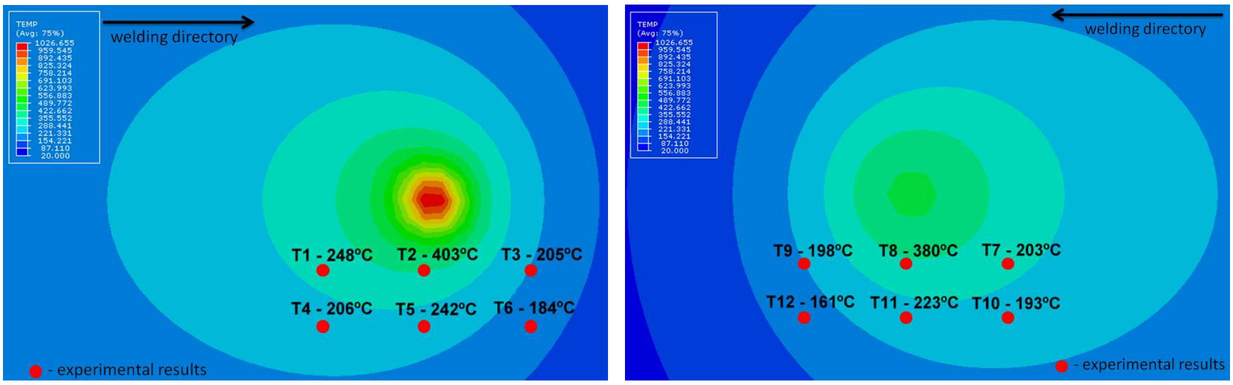


Fig. 4. Comparison of numerical and experimental results for the a) top b) bottom surfaces of the welding material ($W$ = 670 W, $r$ = 3 mm, $U$ = 3 mm/s, $\eta$ = 0.5)

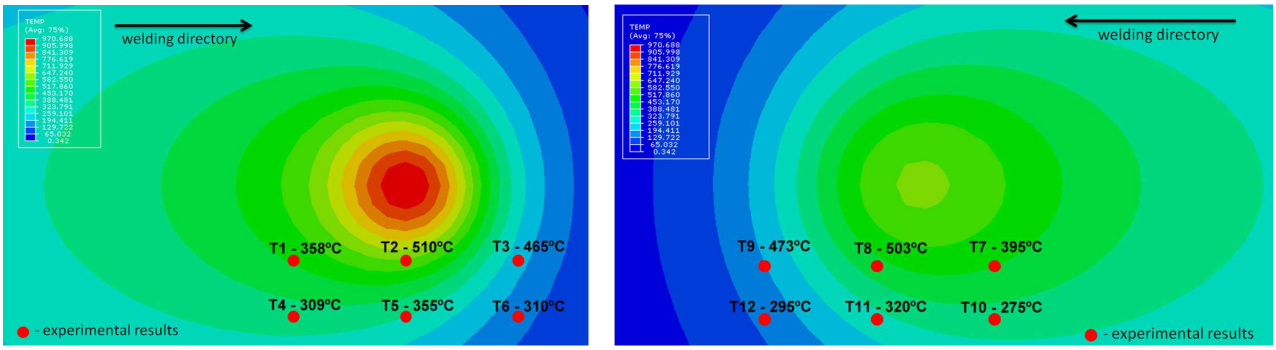


Fig. 5. Comparison of numerical and experimental results for the a) top b) bottom surfaces of the welding material ($Q$ = 975 W, $r$ = 3 mm, $U$ = 7.24 mm/s, $\eta$ = 0.78)

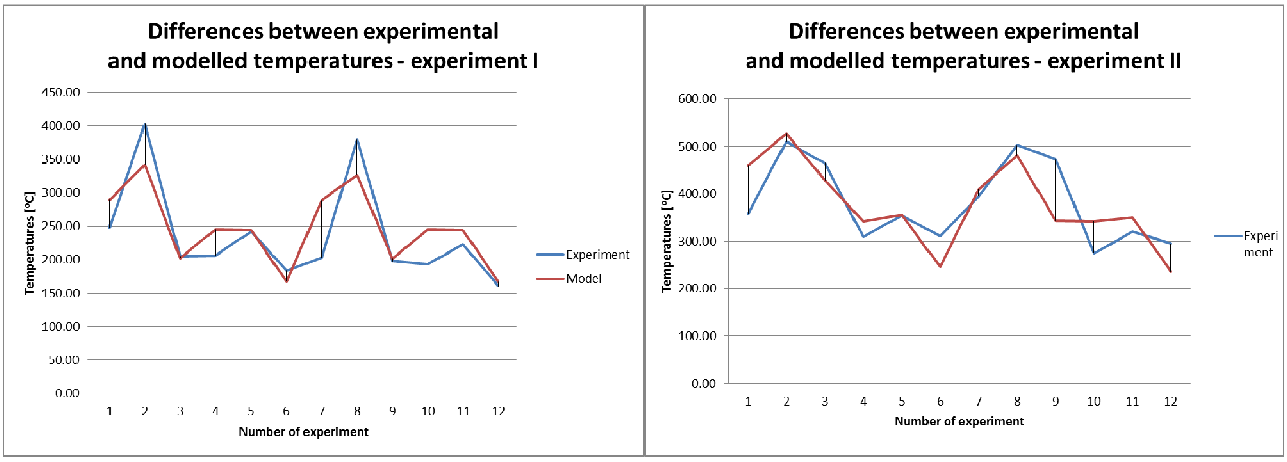


Fig. 6. Comparison of experimental and modelled temperatures in selected points

## 5. COMPUTER SYSTEM FOR WELDING MODELLING

The main objective of this work is to create a computer system for simulation of TIG welding process, which can support production engineers in selection of consumables and optimal process parameters. Similar computer systems were proposed for modelling and optimization of forging [11],[12]. Nevertheless, these computer applications are limited to one numerical engine and their functionality does not cover the processes of welding. The elaborated numerical model of welding was implemented as a part of ABAQUS software in form of user's procedures. ABAQUS as well as other software dedicated to numerical simulations is a part of the proposed computer system supporting design and modeling of TIG welding processes. The deployment of this system is presented in Fig. 7.

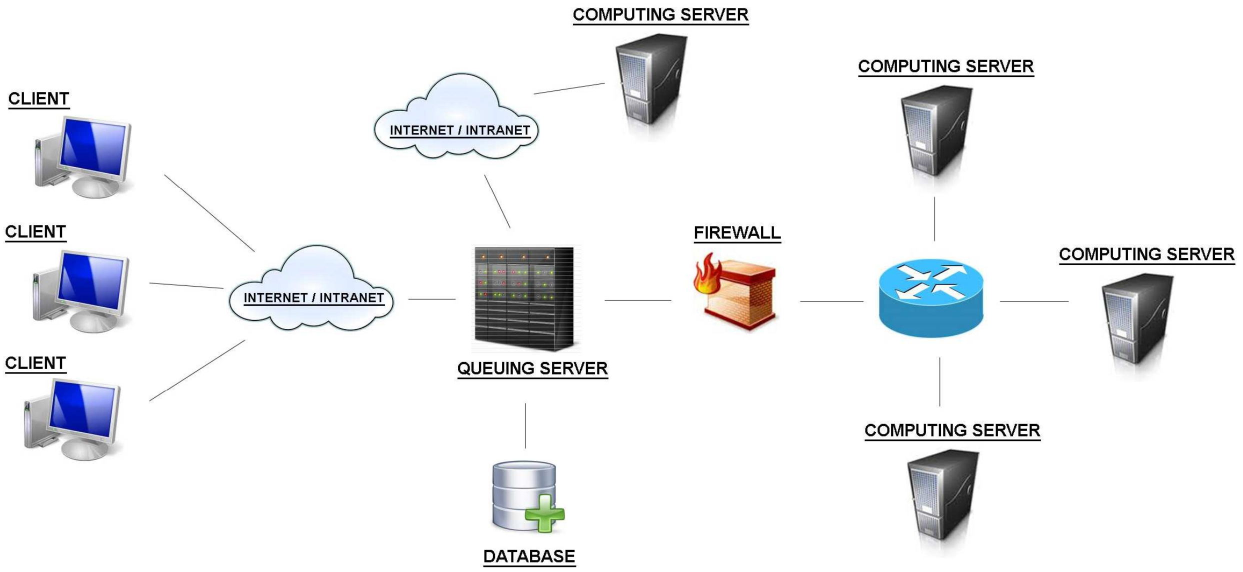


Fig. 7. Deployment diagram of the welding system

According to the deployment diagram, a functionality of the system is implemented in four main modules: queuing, computing and database servers, and client's interface. The implementation details are shown in Fig. 8, which contains the following modules:

- **Queuing server** is the most important part of the system, which consists of two internal servers i.e. web server with generator of user interface and task manager server responsible for queuing of computational jobs. This module obtains request from the external user interface ('Web based GUI' component) in form of designed welding process with all the details related to material, process parameters, tools and boundary conditions. These specific details are downloaded from the database in cooperation of two components ('Process design' and 'Data manager'), and used to describe the process. The request is serialized to XML and stored back in the database. It is also passed to the meshing procedures ('Mesh Generator' component) to obtain finite element meshes imported during the calculations. Finally, the designed process is converted to special input files and passed to the computing server according to the calculated load balance of available equipment ('Queuing' component).

- **Computing server** is responsible for performance of numerical simulations on the basis of generated input files, which are passed to the numerical software e.g. ABAQUS or Morfeo due to communication between ‘Designer’ and ‘Computing’ components. The crucial part of this module is supported by ‘Computing Control’ component, which analyzes the input files and progress of performed calculations. It also gives information about all the errors and obtained results.
- **Database server** implementation is based on ‘Data control’ component, which in cooperation with ‘Data manager’ analyzes the data taking care of their format and coherence. It is implemented with application of interfaces which allow to connect various types of database management engines e.g. MySQL, PostgreSQL or SQLite. Such solution offers the freedom in selection of final engine used as a data storage.
- **Client interface** built of separated views is generated by the web server and then passed to a user. This functionality supports users with different operating systems as well as Internet browsers.

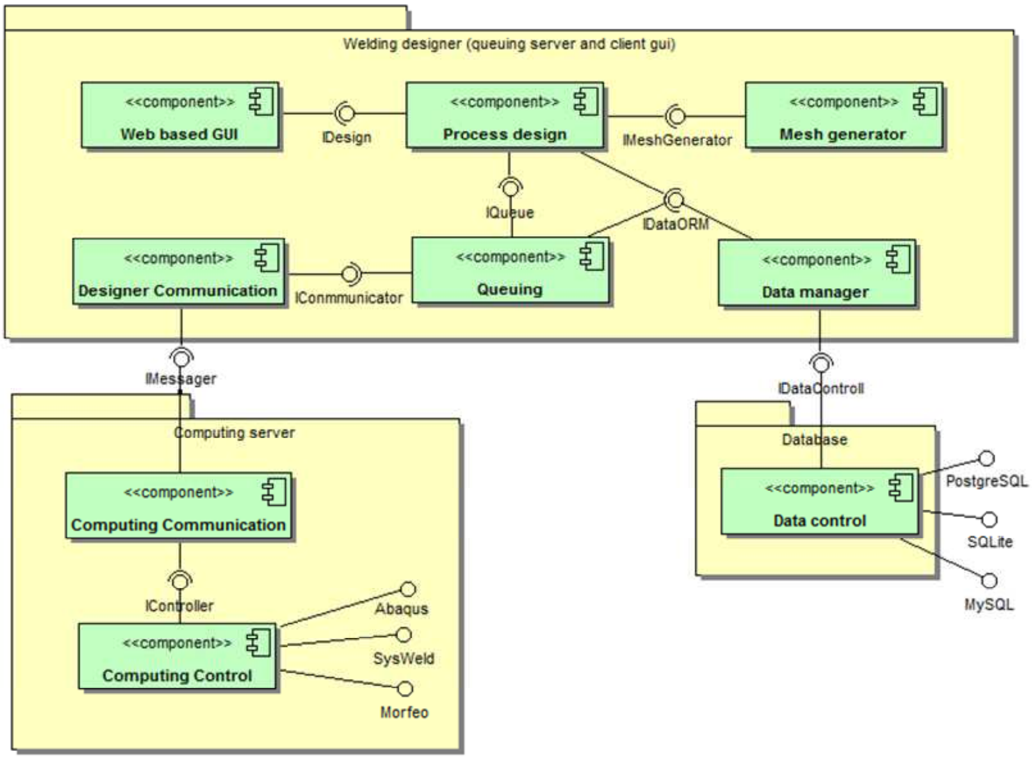


Fig. 8. The component diagram of proposed welding system

## 6. CONCLUSIONS

The flexible computer system for simulation of the TIG welding process is proposed as an engineering support application for Abaqus and Morfeo FEM software. Its functionality has been tuned for the Inconel alloy [5] and for the aluminium alloy [10]. The comparison of numerical results with data available in literature confirms good predictive capability of applied simulation model. The part of proposed system is implemented in ABAQUS in form of internal subroutines, which will be also transferred to the Morfeo program, that is supported by the modular architecture. The preparation of the process description as well as presentation of obtained results is offered by the functionality of graphical user interface communicating with external database. The user interface is implemented and equipped with drag & drop mechanisms, which facilitate the procedure of design of the complex TIG welding process. The system can be used to evaluate the optimal parameters of the TIG welding process.

The computer system is developed to allow optimal adjustment of welding parameters for gas turbine elements that should lead to enhancement of the engine structure reliability.

## ACKNOWLEDGEMENT

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