Calculation of the Heat Affected Zone Coupled with the Arc Simulation in Tig Welding Process Considering the Marangoni Effect

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The present article is focused on a tungsten inert gas (TIG) welding process in two operation regimes, a normal and a constricted one. A computational model is applied for simulations of the liquid weld pool and the heat-affected zone of the workpiece coupled with a simulation of the welding arc. Welding experiments are used for model validation. Temperature profiles obtained from high-speed images with spectral filters correspond well with arc simulation results for both operation regimes.

Keywords: tungsten inert gas welding, constricted arc, arc simulation, weld pool

1 INTRODUCTION

Tungsten inert gas welding with free-burning arc and constricted arc welding have the similar principle of operation. Both electric arcs are burning in inert gas between tungsten non-consumable electrode and workpiece, providing heat to the welded parts. TIG welding is widely applied on the plants (shipbuilding, mechanical engineering) comparing to constricted arc welding. The main reasons are more simple equipment for TIG process and method of its operation. However, the constricted arc has important advantages as large penetration depth, narrow weld seam and narrow heat-affected zone (HAZ). HAZ is a major technology characteristic of the seam in industry due to the big number of welding constructions that are broken not in the melting zone, but in the zone where the metal was heated above critical temperature. Therefore the strength characteristics of welding seam, produced by constricted arc is higher than seams welded by TIG arc. Owing to this great penetrating effect and small HAZ, high-strength alloys for special aims can be welded without additional heating thus increasing mechanical parameters of the seam. Unfortunately for the constricted arcs the methods of the heat transfer control from arc to workpiece is not investigated in detail comparing to TIG welding. Additionally, technical standards need to be elaborated comprehensively.

This work is focused on the development of a stationary two-dimensional arc model for mechanization and optimization of welding technology based on TIG and constricted arcs. For these purpose two arcs with different cathode positions relative to the ceramic nozzle were investigated. Modeled temperature profiles were compared with experimental results.

2 EXPERIMENTAL SETUP

Two geometries of the welding burners (torches) have been chosen for present investigations: i) classical TIG configuration with 3.5 mm stick out of the tungsten cathode from a ceramic nozzle of 11 mm inner diameter and 10 mm arc length; ii) constricted arc configuration with cathode tip inside the nozzle of 6.35 mm inner diameter and 12 mm inter electrode distance. For both configurations a tungsten cathode of 3.2 mm in diameter was used. The second configuration has similarity with a plasma welding process. However, a second nozzle as typical for plasma welding was not applied in order to simplify the experimental arrangement.

A commercial power supply with current stabilization has been used for experiments. A steel (S235) workpiece, 10 mm thick, worked as anode. The current for both cases is 100 A. The voltage of the TIG arc was 14-15 V whereas in the case of the constricted arc it was higher 19-20 V. Argon was used as shielding inert gas with the flow rate 12 l/min. The arc was observed with a high-speed camera in the spectral region 812±2 nm selected by an interference filter. In the selected spectral range two spectral lines of neutral argon (810 nm and 811 nm) contribute to the camera signal. Knowledge of the filter transmission and calibration of the camera response with tungsten band lamp allow apply a standard technique of the temperature determination [1] based on assumption of local thermodynamic equilibrium (LTE). The photographs have been used for determination of the temperature profiles in the middle of the inter electrode distance and at 1 mm above workpiece, see Fig. 1. The photographs are presented in Figs. 2 and 3.

3 SIMULATION METHOD

The simulation model of the arc and weld pool was developed using software ANSYS CFX and assuming LTE of the arc plasma. The governing equations for mass continuity, momentum conservation, energy conservation, and current continuity coupled with Ohm's law and Maxwell's equations have been considered. Also, the forces acting on the weld pool, such as drag force by the arc, buoyancy, electromagnetic force and Marangoni force that occurs due to the gradient of the surface tension were taken into account [2, 3, 4]. Compared to the previous simulations [3, 4], the heat balance of the tungsten cathode has been solved. Furthermore, the revised pressure due to the concentration of the constricted arc [5, 6] has been considered for the weld pool and HAZ profile calculation. The results are presented in Figs. 1-3.

4 RESULTS AND DISCUSSIONS

The calculated temperature profiles show a good agreement with the measured ones, see Fig. 1. The temperature of the constricted arc is significantly higher in the arc axis and decreases faster with the arc radius in comparison to the TIG configuration. At the arc edge deviation from thermodynamic equilibrium is expected [7]. At large distance from the arc axis the calculations provide gas temperature whereas spectroscopic measurements reflect electron temperature.

Notice, that the improved model leads to a better agreement between simulated and measured temperature profile in comparison with previous work [3,4].

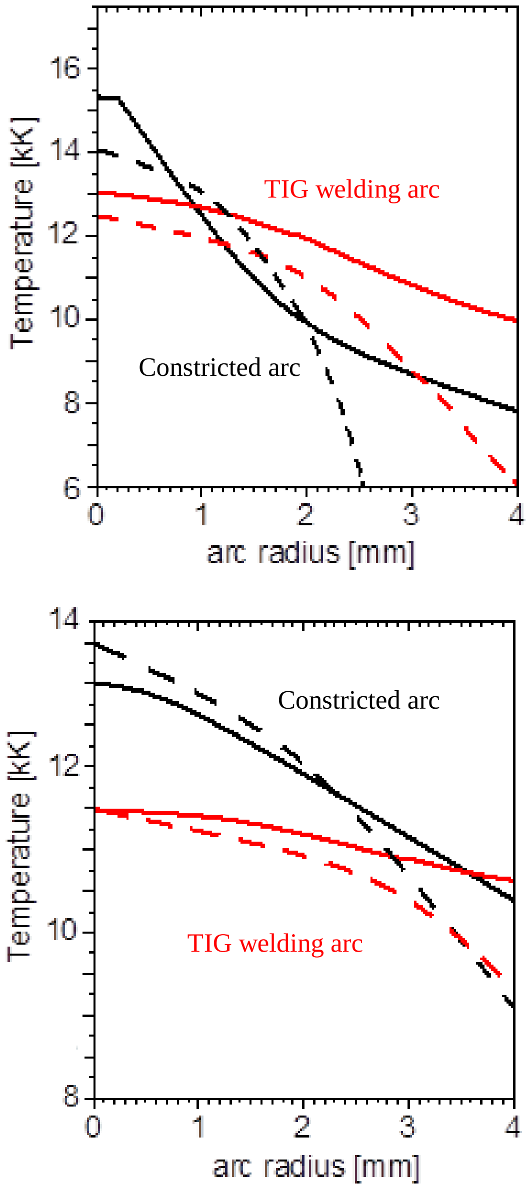

Fig. 1: The experimental result (full line) of TIG welding arc and constricted arc temperature with calculated result (dash line) for the middle of arc (top picture) and for 1 mm above the anode (bottom picture)

In Figs. 2 and 3 the simulation results are presented more comprehensively. On the right side of the figures photographs of the high-speed camera are shown. The calculated shape of the arc corresponds well to the photograph. It can also be seen that in the second configuration the arc is narrower and the layer near the anode is not so fuzzy like in TIG welding case.

The workpieces in Figs. 2 and 3 are presented by two pictures: on the left side the weld pool is indicated by a white domain, and after a black border the HAZ is shown as a grey domain. On the right side the temperature profile is given by isotherms. The HAZ is determined from the temperature profile in the workpiece considering dangerous temperature of overheating and decreasing of seam strength parameters for usual steel - between 770 K and melting point.

5 SUMMARY

The calculated parameters of the weld pool demonstrate: due to the more concentrated heat flux and the higher flow velocity of the constricted arc the pressure on the surface of melted steel is increased. Also the convective and conductive components of the power flux from the arc to the work piece are larger.

As the result, the weld pool is deeper and, at the same time, the HAZ is much smaller in case of the constricted arc.

The simulation model is in agreement with experimental results for the arc temperature and enable to calculate optimal parameters of constricted arc welding. Therefore, it can be used to form technical demands for the control of the heat flux depending on the welded material and it's thickness. It supports increasing quality and predictability of the welding seams.

The modification of the model, described in the simulation method, provides more accurate results of the arc temperature, weld pool and HAZ profile.

Using the present simulation model based of LTE assumption the process of switching to other geometry or welding parameters is simplified for industrial tasks comparing to non-equilibrium modelling [7].

In next steps of investigation the welding parameters of the constricted arc required for industry will be examined, and the predicted weld pool and HAZ will be discussed.

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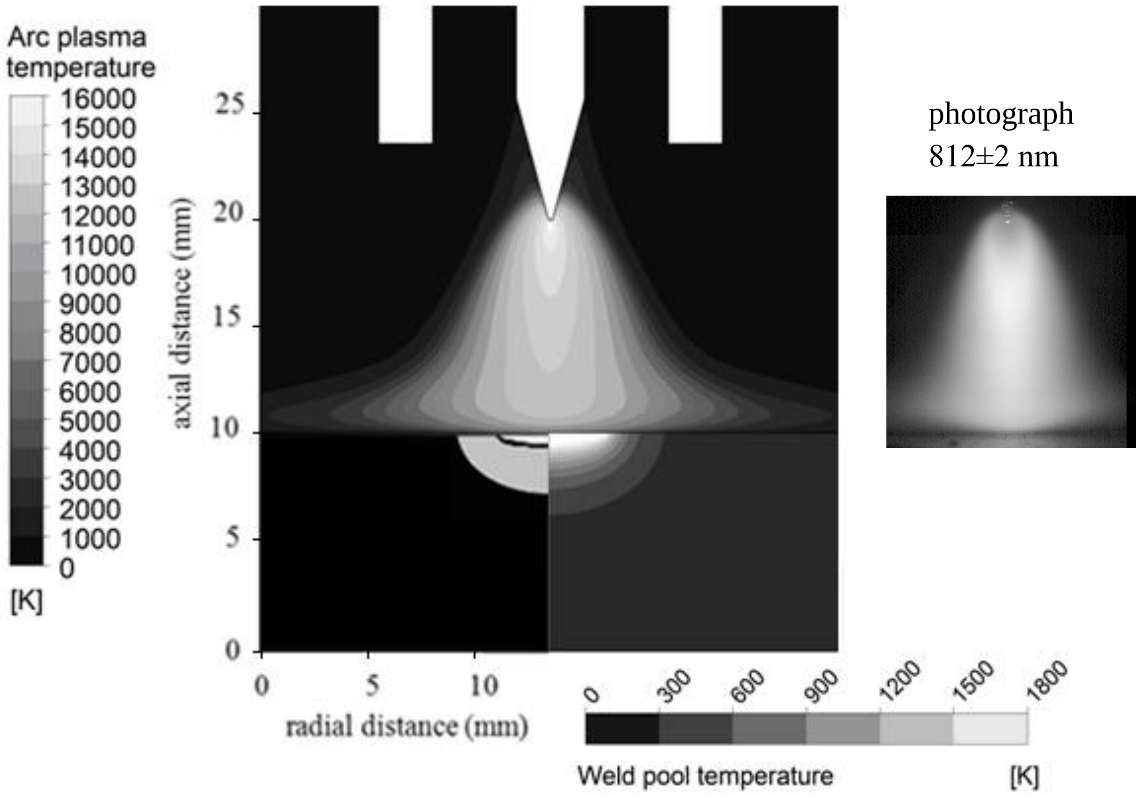

Fig. 2: Calculation result (left) and photograph (right) for TIG welding

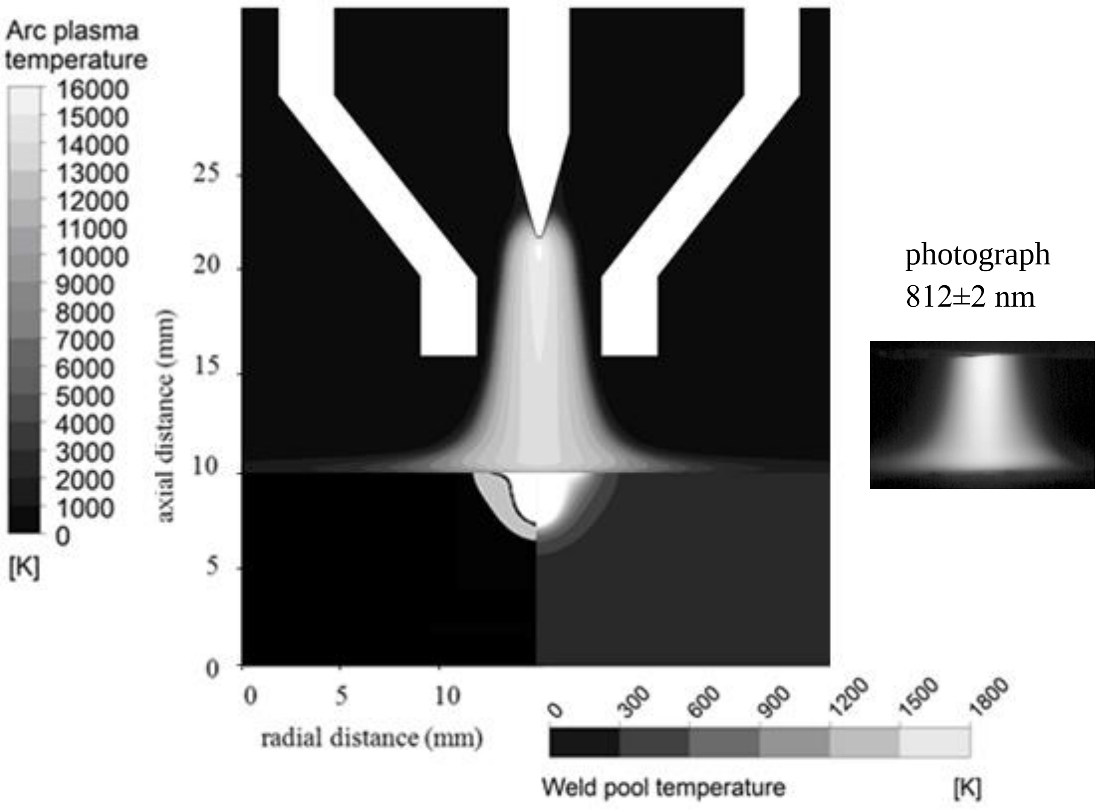

Fig. 3: Calculation result (left) and photograph (right) for constricted arc welding