Numerical simulation of the shielding gas flow with GMA welding and options of validation by diagnostics

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Abstract

GMA welding is still one of the most frequently applied welding techniques in the industry. Particularly the joining of aluminium, high alloyed steels or titanium requires a cover of shielding gas in order to provide a low PPM concentration of oxygen. Thus, the result of the welding process depends essentially on the physiochemic and fluidic properties of the used process gas. Consequently, it is necessary to be able to describe and to analyse its flow with reference to various influencing variables. However, it is very difficult to realize this during arc welding processes. A poor visibility is caused by the covered areas inside the welding torch, temperatures up to 20,000 K, the high radiation of the arc and the electromagnetic field. The appliance of a modern numerical welding process simulation offers the possibility to describe the complex physical correlations economically and fast with a high resolution.
This article introduces a model, that was used for the visualization of the flow of the shielding gas in order to make statements about the flow conditions inside the welding torch and the concentration of oxygen at the workpiece. Furthermore, the possibilities of a measurement with gauging the oxygen and the Schlieren technique are described.

1 Introduction and state of the technology

GMA welding is used as a semi-automatic or automatic arc welding process in many applications. In this process the arc is burning between a continuous and consumable wire electrode and the workpiece. The used shielding gas assumes a lot of tasks, for example the cooling of the torch, the definition of features of the arc or the protection of the melt from oxidation. Particularly the joining of aluminium, high alloyed steels or titanium requires a cover of shielding gas in order to provide a low PPM concentration of oxygen; otherwise costly rework cannot be avoided. Furthermore, the shielding gas transports metal vapour, dust and fume into the working environment. In summary, the shielding gas flow is so important, that it is essential to analyse its characteristics in detail and in context with the other process components. A poor visibility is caused by the covered areas inside the welding torch, temperatures up to 20,000 K, the high radiation of the arc and the electromagnetic field. The description of the shielding gas flow is not a trivial problem and measurements are limited. The construction parameters of current GMA welding torches [2, 3] and developments associated with the shielding gas flow [9] are mostly determined by experiments, which visualised the shielding gas flow without the arc. In reference [20] the use of the Particle Image Velocimetry (PIV) with GMA welding is described. In this way it is possible to analyse two-dimensional flow fields. There are results with the open jet of short arc, impulse arc and spray arc.[6, 20] The PIV is also part of this study, but won't be discussed in this article. In addition the flow field can be described by the Schlieren technique [8] and by gauging the oxygen it is possible to measure the concentration of oxygen directly next to the arc [5]. All these measurement methods are the base to deploy and to validate the multifaceted options of the numerical simulation. It affords the description of complex physical processes with a local and temporal high resolution. Therefore it is able to describe the shielding gas flow inside the torch, where no measurement is adaptive. Although recent simulation models of GMA welding processes include the arc as well as the drip transition, they just can be applied to a perfect cover of shielding gas within an atmosphere of 100 % argon. [7, 11, 16, 17] In reference [4] a model was used, which allows statements of the shielding efficiency and fume extraction of a GMA welding torch with the arc, but the arc is modelled as a frustum regarding only the thermal influence. In addition it is unclear, if a turbulence model was applied. Speiseder [17] compares calculated flow fields in ANSYS CFX with PIV measurements. The good accordance between the measurement and the model even with a simple arc model and without metal vaporisation can be shown. But only qualitative statements about turbulent and diffusive contamination of atmosphere could be given. The model in ANSYS CFX was developed within the last few years and now it is able to regard diffusion processes and complex models of the arc. [15]

2 Grid requirements and Modelling

It is necessary to develop a special grid for modelling a GMA welding process with the aim to valuate the shielding gas flow and the atmosphere contamination. Areas that are relevant for the gas flow have to be very fine, whereas areas of little significance can be rather coarse-meshed. The grid will be gradually improved until the results are in a metrological validated range and change only insignificantly through further improvement. However, in some parts of the grid this high solution is not necessary and can be systematically reduced. It is feasible to reduce the computing time without losing quality of the results.

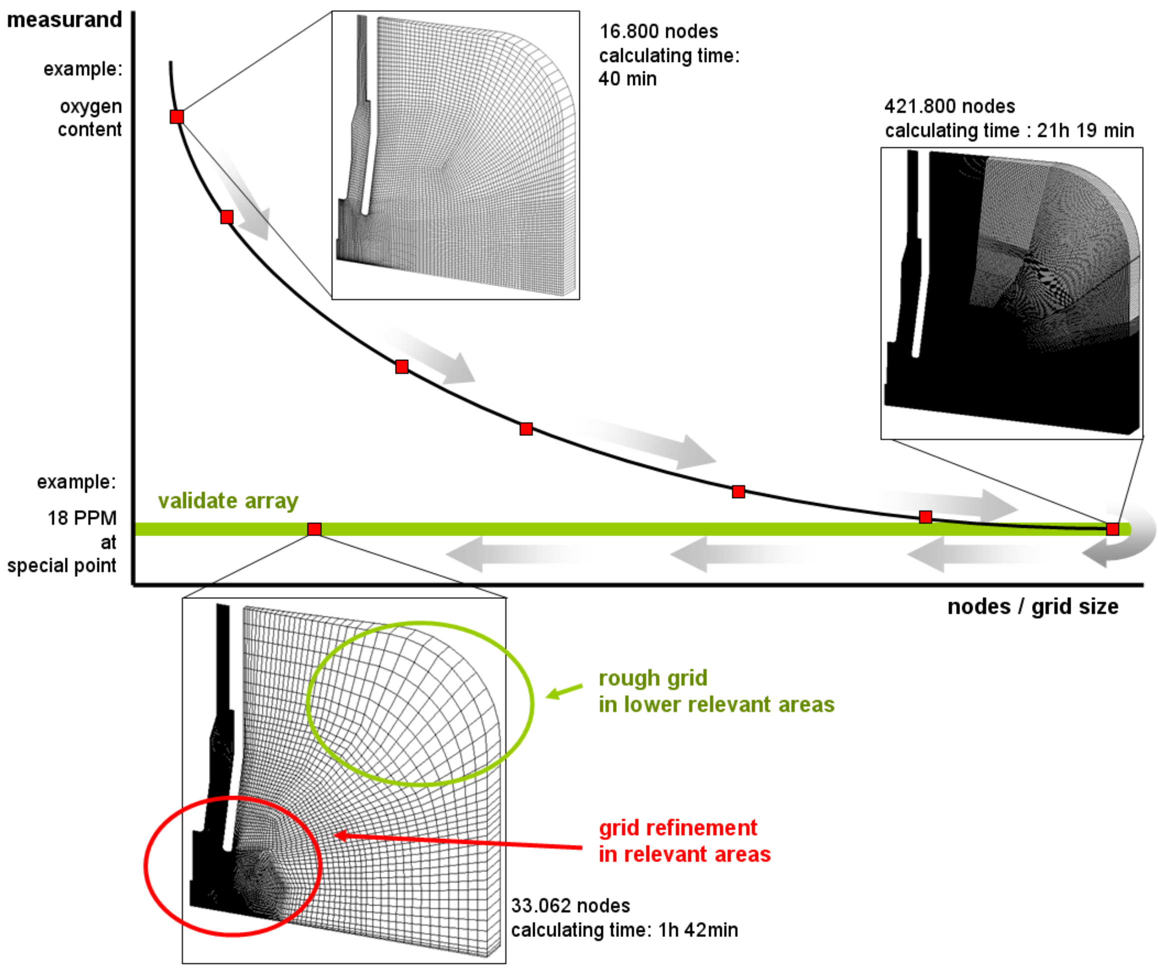

Fig. 1: Proceeding for creating a computational grid with the GMA welding torch

Especially the regions above the gas nozzle and the wall near regions of workpiece are important.

Apart from solving continuity equations, moment or energy balances and equations of the arc model a turbulence model will be integrated and the diffusion of argon in the air will be described by a transport equation. The effects of the arc on the flow of the gas are analysed. The metal vaporization is also part of the research [14], but will not be discussed in the present article. Figure 2 shows the geometry of the used GMA welding torch and the names of the domains.

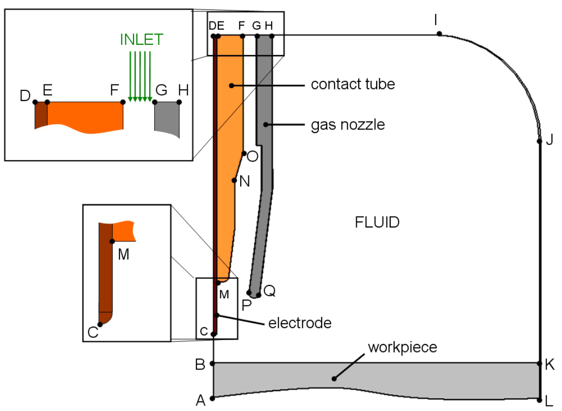

Fig. 2: 3° model of a GMA welding torch

In the first step, the gas flow was calculated without the arc. All interfaces between the fluid and the solids are taken as no slip walls with a temperature of 300 K. To research the contamination of the shielding gas by turbulence mixing a turbulence model is used according to the state of technology. Different turbulence models were compared (none, k-Epsilon, k-Omega, SST, BSL, SSG,). The present article applies a two-equation turbulence model (Shear-Stress-Transport / SST) from the series of turbulent viscosity models, which is based on the Navier-Stokes equation (RANS). It is advanced from the k-Omega model of Menter [12] and combines advantages of various two-equation turbulence models in areas close and far from the wall [1, 10]. In this case the SST model is the most advantageous.
The diffusion in the gas mixture of argon and air will be calculated by the stated transport equation (1) and the temperature-dependent kinematic diffusivity. [13]

Argon transport equation [17]:

$$\frac{\partial\left(\rho Y_{Ar}\right)}{\partial t}+\nabla\left(\rho\vec{u}Y_{Ar}-\rho D_Y\nabla Y_{Ar}\right)=0 \quad (1)$$

with:
mass fraction of argon Y_{Ar}
density of the mixture ρ
velocity vector $\vec{u}$

It is assumed that argon flows at the inlet with a volume concentration of 99.996 %. At the beginning the fluid contains an air concentration of 100 %. The concentration of oxygen is calculated as a consistent proportion of 23.135 % of air.
The implementation of the arc model is obtained by the physical model of magnetohydrodynamics (MHD). The conservation equations of the flow (Navier-Stokes equation) are combined with the equations of electromagnetism (Maxwell's equation) and solved in ANSYS CFX. The resistance heating and the magnetic field that is caused by the electrical power are considered. The Lorentz force produced from the current flow and the magnetic field act on the fluid.[19] The boundary conditions are named in table 1.

Table 1: Boundary conditions of GMA welding model with MHD

region	**type**	**T**	**magnetic potential**	**electric potential**	$\dot{m}_{SG}$ **/ rel. pressure**	**slip**
INLET F-G	Inlet	300 K	$\frac{\partial A_x}{\partial n}=\frac{\partial A_y}{\partial n}=\frac{\partial A_z}{\partial n}=0$	$\frac{\partial \Phi}{\partial n}=0$	10 l/min	-
electrode-TOP D-E	Wall	400 K	$\frac{\partial A_x}{\partial n}=\frac{\partial A_y}{\partial n}=\frac{\partial A_z}{\partial n}=0$	18,8 V	0	-
contact tube-TOP E-F	Wall	400 K	$\frac{\partial A_x}{\partial n}=\frac{\partial A_y}{\partial n}=\frac{\partial A_z}{\partial n}=0$	-	0	-
gas nozzle-TOP G-H	Wall	300 K	$\frac{\partial A_x}{\partial n}=\frac{\partial A_y}{\partial n}=\frac{\partial A_z}{\partial n}=0$	-	0	-
FLUID-electrode C-M	Interface	flux	flux	flux	0	no slip
FLUID-workpiece B-K	Interface	flux	flux	flux	0	no slip

region	type	T	magnetic potential	electric potential	$\dot{m}_{SG}$ / rel. pressure	slip
FLUID-gas nozzle G-P-Q-H	Interface	flux	flux	$\frac{\partial \Phi}{\partial n} = 0$	0	no slip
FLUID-contact tube M-N-O-F	Interface	flux	flux	$\frac{\partial \Phi}{\partial n} = 0$	0	no slip
electr.-cont. tube E-M	Interface	flux	flux	$\frac{\partial \Phi}{\partial n} = 0$	0	-
OPENING H-I-J-K	Opening	300 K	0.	-	p_0	-
workpiece-wall K-L	Wall	400 K	0.	$\frac{\partial \Phi}{\partial n} = 0$	0	-
workpiece-bottom A-L	Interface	$\frac{\partial T}{\partial n} = 0$	$\frac{\partial A_x}{\partial n} = \frac{\partial A_y}{\partial n} = \frac{\partial A_z}{\partial n} = 0$	0.	0	-

3 Diagnostics

In order to validate the results of the simulation, diagnosis methods were used and developed. The methods are described in the following passage:

3.1 Schlieren technique

The Schlieren technique is based on the differences of the density caused by the flow in transparent media. The change of density caused to a deflection of the light beams, because of changing the refractive index. In this way are compressible turbulences and atmosphere turbulences visualized. Because of the high radiation the Schlieren technique is conventionally used without the arc. But the influence by the arc is so important, that it is essential to comprehend it. Special mirrors, lenses, apertures and filters make this possible.

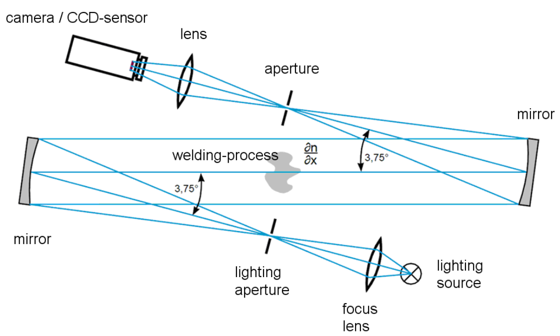

Fig. 3: Set up of a Schlieren test station

The method was used with TIG and plasma welding processes [8] and is applied to GMA welding at time. Similar to the PIV measurement results, the Schlieren pictures can be compared with the simulation results. The set up of the Schlieren technique is relative easy to handle and the shielding gas flow is not influenced by the measurement method. The main objectives are the characteristics of global flow not quantitative information about special values like velocity or temperature.

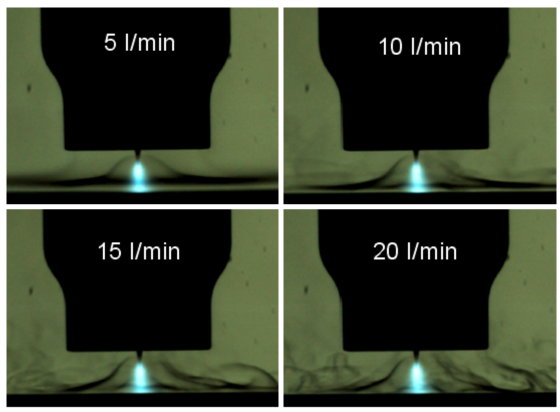

Fig. 4: Pictures of TIG Processes with various amounts of shielding gas

Figure 4 shows pictures of a TIG process with different amounts of shielding gas. (Ar50/He50). The increasing appearance of turbulent flow becomes obvious in the pictures.

3.2 Gauging of oxygen

The defined extraction of a marginal amount of gas by suction directly next to the arc and the appliance of the lambda sensor principle permit gauging of the oxygen concentration at the workpiece./5/ With TIG-processes the arc is burning on a cooled copper plate. In this assembly there is a small bore (0.5 mm bore diameter) and the arc is guided over the bore hole. The continuously sucked off gas stream (in middle 0.15 l/min) is analyzed by the sensor and the concentration of oxygen can be measured. With GMA welding processes it is more difficult because the melt would clog the bore hole. To avoid this, a special formed tungsten electrode is brazed in the contact tube instead of the wire electrode and so the process is approximately emulated. To suck off a gas stream from the near of the electrode, it is imaginable to place a slender duct into the arc.

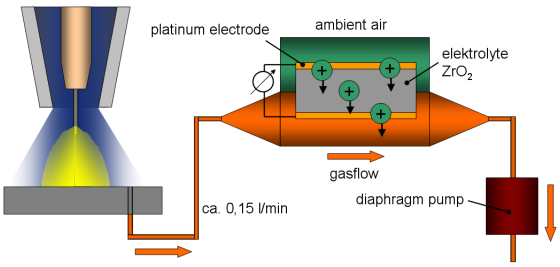

Fig. 5: Set up of Gauging the oxygen

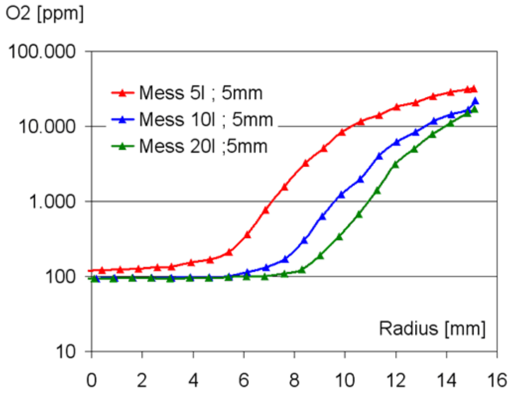

Fig. 6: Measurement results (without arc)

4 Results

It is assumed that the gas distribution with GMA welding processes is nearly axially symmetrical. However, the typical construction of standard GMA welding torches leads to the assumption that the high flow velocity evokes turbulent circumstances in the borehole, which also affect the cover of shielding gas at the workpiece. In order to question the inflow conditions at the inlet and accordingly to evaluate the measurement results, the flow was considered above the inflow cross-section, described in the model. A model without the arc was used for these analyses. The simulation of the gas flow shows the formation of turbulences and their effect on the workpiece. It is proved that it cannot assume an axially symmetrical gas distribution. The laminar and steady inflow conditions at the inlet have to be assumed for reasons of simplification.

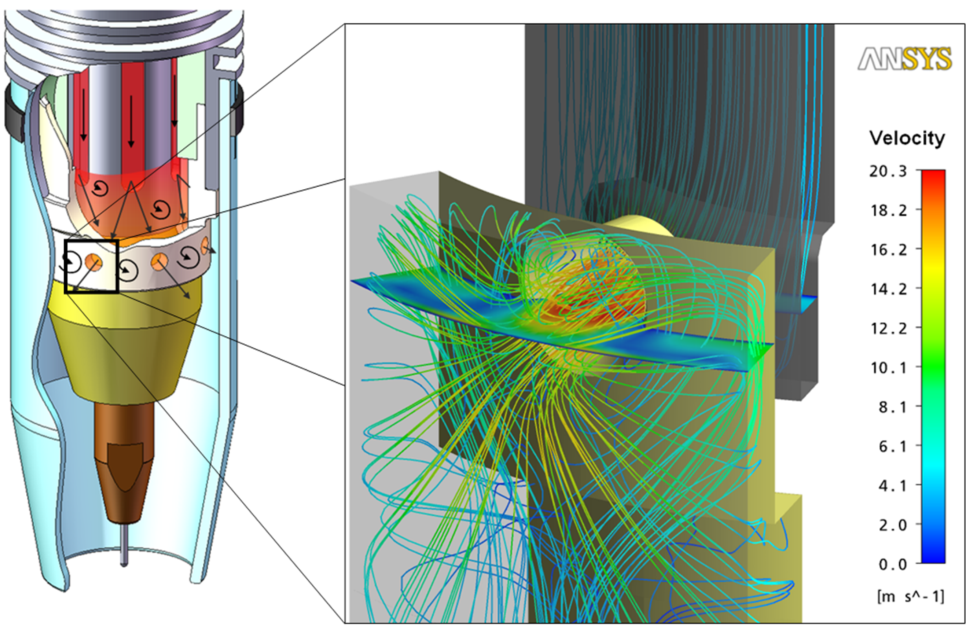

Fig. 7: Gas distribution in the upper part of the welding torch (Argon 10 l/min)

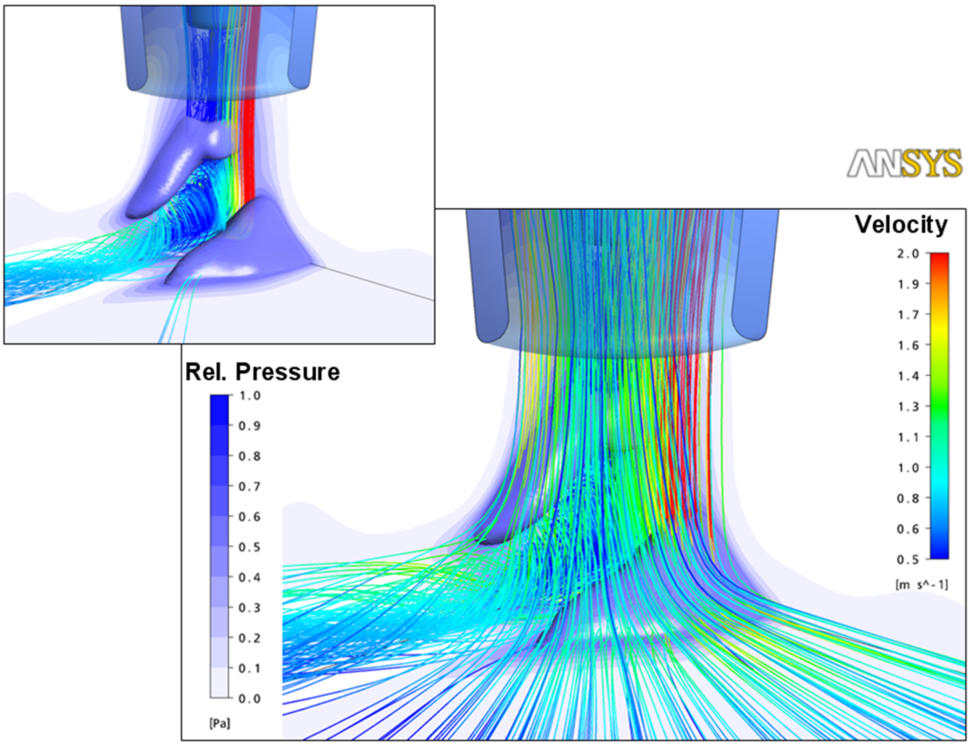

Fig. 8: Effects of the turbulent inflow at the workpiece without the arc

The comparison between flow conditions with and without the arc makes clear that the gas is strongly accelerated by the influence of the high temperatures and the Lorentz force. Moreover, the flow direction below the contact tube changes. Without the arc model a gas flow of little velocities streams from workpiece to the contact tube. Regarding to the arc, the direction changes and velocities up to 280 m/s within the arc are calculated. The gas is accelerated towards the axis of the arc and flow off in axially parallel direction to the workpiece.

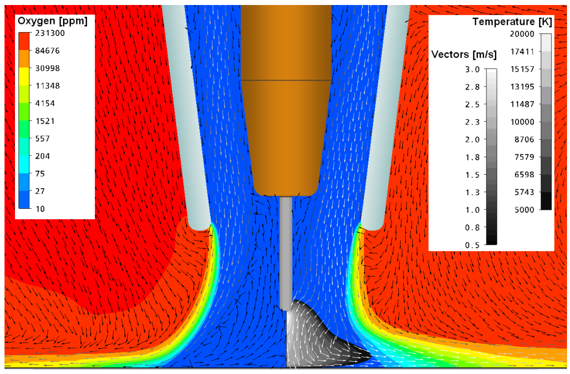

Fig. 9: Proportion of oxygen of the gas flow with (on the right) and without the arc (on the left), argon mass flow 10 l/min

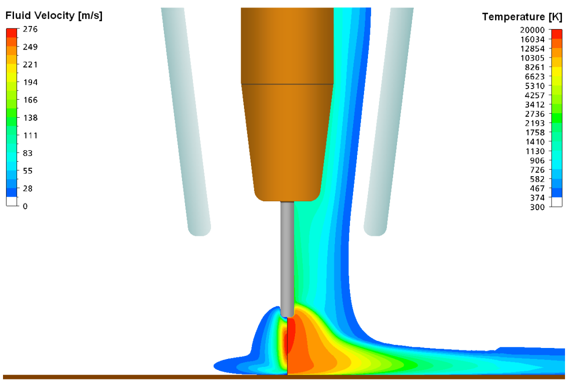

Fig. 10: Velocity (on the left) and temperature (on the right) in the fluid with the arc model, argon mass flow 10 l/min

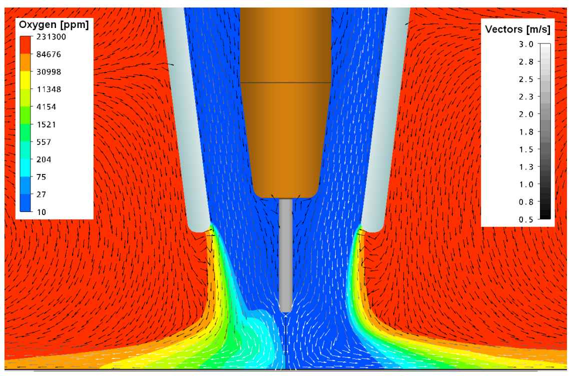

Fig. 11: Argon mass flow 5 l/min (on the left) and 10 l/min (on the right) with the arc

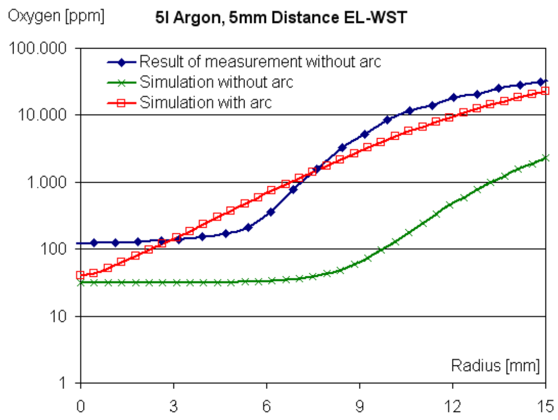

Fig. 12: Comparison of measurement and simulation (Argon 5 l/min)

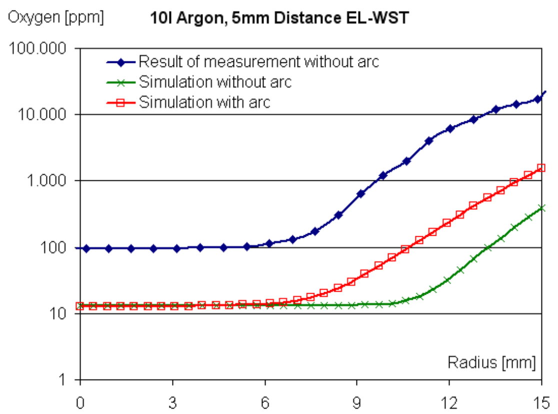

Fig. 13: Comparison of measurement and simulation (Argon 10 l/min)

Figures 12 and 13 show the results of the measurement and the mass fraction of oxygen in the simulation. The lower concentration of oxygen in the simulation is caused by the assumption of ideal, axially symmetrically conditions. Furthermore, the simulation is aimed to refer to the missing observance of the measured gas flow.

5 Conclusion

The article introduces a numerical model that visualizes the flow of the shielding gas and that permits a characterisation of the shielding gas cover at the workpiece. It was proved that high flow velocity at the gas distributor or rather the resulting turbulences significantly affect the flow conditions at the workpiece. The concentration of oxygen at the workpiece was calculated and could be partly validated by the lambda sensor principle. The model allows statements about atmosphere turbulences within the shielding gas flow. The article also introduces diagnostic methods facilitating a validation of the results of the simulation by the measurement. In the further progress these methods will be improved for the use of GMA welding. The aim of this research is to develop a GMA welding torch, which regards all the comprehensive statements, acquired by the appliance of the numerical simulation.

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