

# PREDICTION OF WELD QUALITY WITH EXPANDED WELDING PROCESS ANALYSIS BY SIMWELD AND WELDWARE FOR GMA WELDING

T. LOOSE\*, O. MOKROV \*\*, A. SCHARFF\*\*\* and U. REISGEN\*\*

*\*Ingenieurbüro Tobias Loose, Wössingen, loose@tl-ing.de, www.tl-ing.eu*

*\*\*Institut für Schweißtechnik und Fügetechnik (ISF) der RWTH Aachen, oleg.mokov@isf.rwth-aachen.de,  
www.isf.rwth-aachen.de*

*\*\*\*SLV Mecklenburg-Vorpommern GmbH, scharff@slv-rostock.de, www.slv-rostock.de*

## ABSTRACT

One task of the welding engineer is the supervision of weld quality. Specially for welding of low alloyed steel or high strength steel the management of temperature and heat input has the main impact of the weld and its state concerning the microstructure and the mechanical properties after welding. The weld pool geometry is driven by the machine settings. Due to the quality of a weld and its applicability a sufficient penetration depth and the avoiding of undercuts have to be guaranteed.

The prediction of the local temperature field, the weld pool evolution and the penetration requires a welding process analysis. SimWeld® is specialized in this task and optimized for a fast simulation. The software is designed for industrial application.

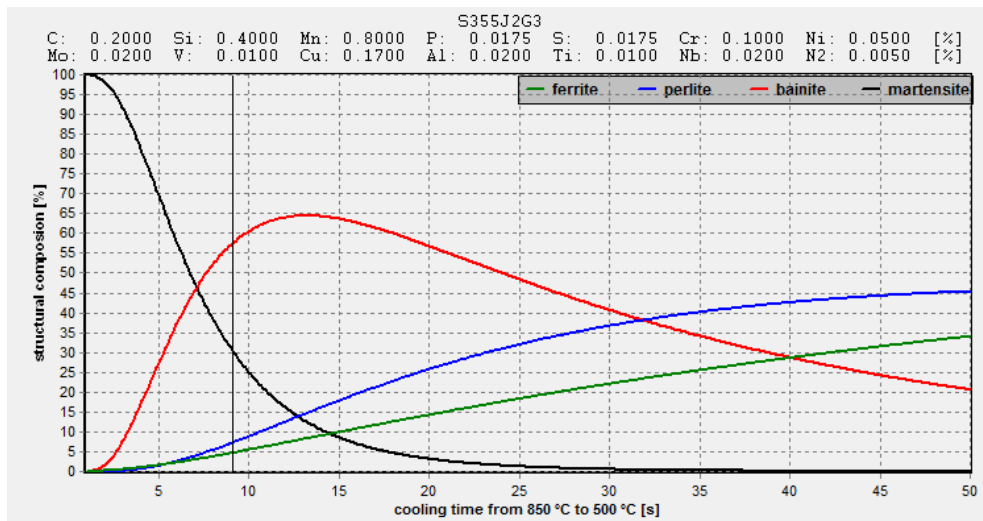
WeldWare® provides CCT-data for unalloyed, low alloyed normal as well as high strength steels for any chemical analysis within the given data range. The CCT-data are expanded by mechanical properties at room.

To predict the microstructure in the weld and heat affected zone the cooling time is needed. This information provides the welding process analysis. With an expansion of the welding process analysis by evaluating the information of the material simulation a prediction of the state of the weld concerning geometry as well as mechanical properties and microstructure is possible.

## WELDWARE®

WeldWare® is a modular welding advisory system, which serves the calculation of heat procedures in welding. It accesses a comprehensive metallurgical data base concerning transformation of microstructure and mechanical properties in weldments of steels and takes

into consideration by this the dependence of steel sort, chemical composition and their scattering, cooling times, mixture ratios, transition coefficients and other technological influence factors.



**Fig. 1** Phase proportion according to cooling times for steel S355J2G3 (1.0570)

The chemical composition is the fingerprint of the material. From the viewpoint of an material engineer a steel grade contains a family of materials which have different behaviour in microstructure and phase change during thermal loading. The choice of the steel grade is the first task in WeldWare® followed by the definition of the chemical composition for the desired steel charge. The composition is checked if their values are in the range which is valid for the applied regression functions in WeldWare®.

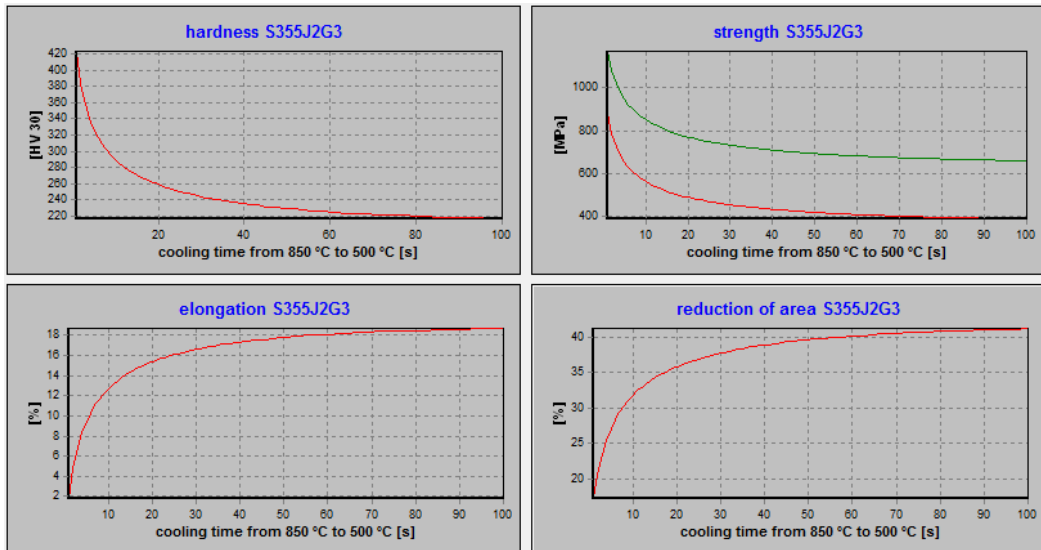
WeldWare® considers cooling times for the temperature range 850 °C down to 500 °C.

The CCT-module provides the CCT-graph, the transformation temperatures Ac1 and Ac3 for the austenitisation as well as the ferrite-start-temperature, bainite-start-temperature and martensit-start-temperature for transformation back to the ferritic phases while cooling. WeldWare® also calculates the phase proportion at several cooling rates. The evolution of single phases martensit, bainite, perlite and ferrite according to the cooling rate is printed in a graph too (Fig 1). This graph provides also the cooling time where the critical martensit proportion is reached (“K30”-value: cooling time which leads to maximum 30 % of martensite).

In case of welding the thermal cycles within the heat affected zone have strong temperature gradients. No holding times exists. The phase transformation is mainly driven by the cooling time.

The mechanical properties yield strength, ultimate strength, hardness, ultimate strain and the reduction of area at fracture point are part of WeldWare® database too. WeldWare® computes these parameters according to several cooling rates with its module mechanical properties. Fig. 2 shows the graphic of these properties. The mechanical properties are

determined only on the base of thermal cycles (and steel composition). Plastic strains which causes an increase of the yield strength by strain hardening is not taken into account.



**Fig 2:** Mechanical properties according to cooling rates for S355J2G3 (1.0570)

An interface provides the material data from WeldWare<sup>®</sup> for any Finite-Element-Analysis (FEM) [1]. The export is written in an ascii-file with the extension wwd (weld-ware-data). After the steel grade and the designation of the heat defined by the user the chemical composition is printed to give the data sheet an unique identifier.

The next block defines the start- and end-temperatures of the phase transformations. The WeldWare<sup>®</sup> temperature range for the cooling time is printed to.

Twenty discrete cooling times from 1 s to 1000 s in logarithmic order are chosen to print out the temperature rate depending data:

- phase proportion of ferrite
- phase proportion of perlite
- phase proportion of bainite
- phase proportion of martensite
- yield strength
- ultimate strength

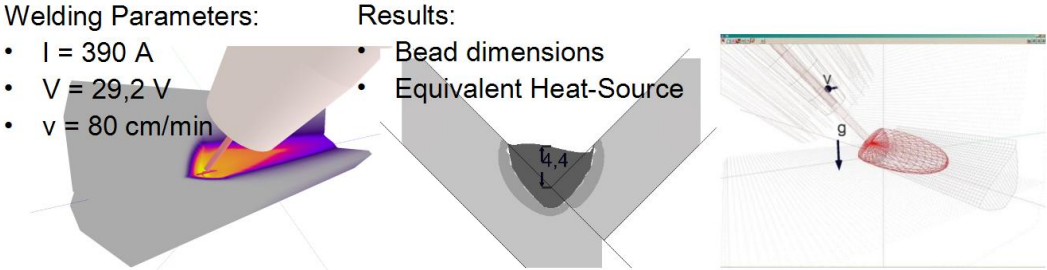
Ultimate strain and hardness will be printed in the next version of WeldWare<sup>®</sup> too.

With these data all information exists to describe microstructure and mechanical properties of the weld and its heat affected zone. The only information missing is the cooling

time at each point of the cross-section. This information can be provided by a welding process analysis with SimWeld:

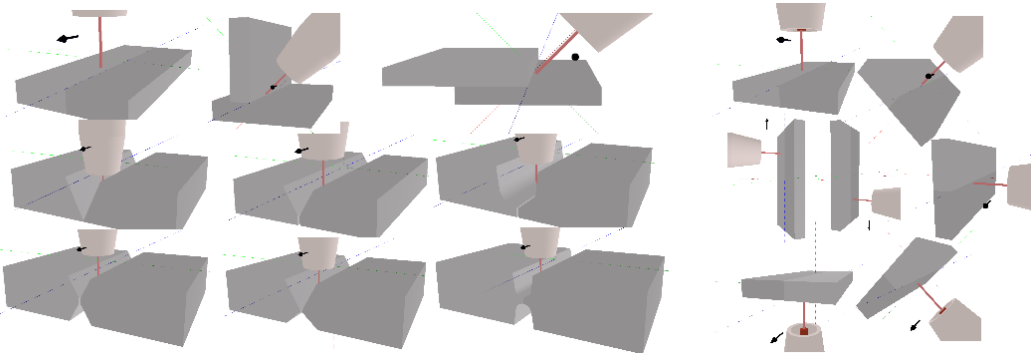
### SIMWELD

SimWeld as a software for the simulation of gas metal arc welding has been developed continuously through research and industry projects for about 25 years. SimWeld is highly specified to its application, for this the simulation time of less than 1 minute is extremely short. The welding engineer can predict the weld pool geometry and its quality according to the process parameters and machine settings. The equivalent heat sources are calculated with every SimWeld (Fig.3) simulation and can be used for the welding structure analysis.



**Fig 3.** SimWeld Simulation

The simulation domain is automatically limited to the area where the local temperature field has an impact. SimWeld provides a 2,5D Simulation, which means the geometry is defined as cross section only, but in the simulation the 3rd dimension is taken into account by linear extrusion.



**Fig. 4** Weld Preparations and Work Positions in SimWeld

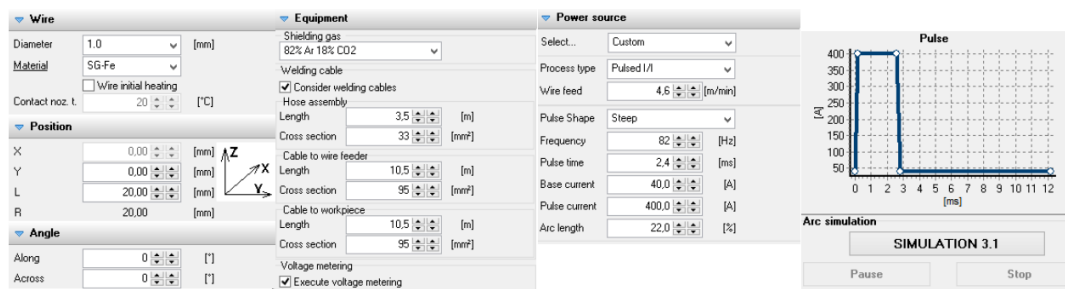
SimWeld provides all weld preparations according to international standardization (ISO 9692). The first task is to define the local geometry of the weld, the work position

(Fig. 4) and the material. Steel, inoxidable steel and aluminium are available. The given database can be adapted or extended with user data. Apart from the predefined work position, the user can define any other position as well.

SimWeld 2015 is limited to the simulation of the groove weld. If the equivalent heat source needs to be defined for other layer or any non defined geometry the geometry shall be approached by a flat plate with equivalent thickness.

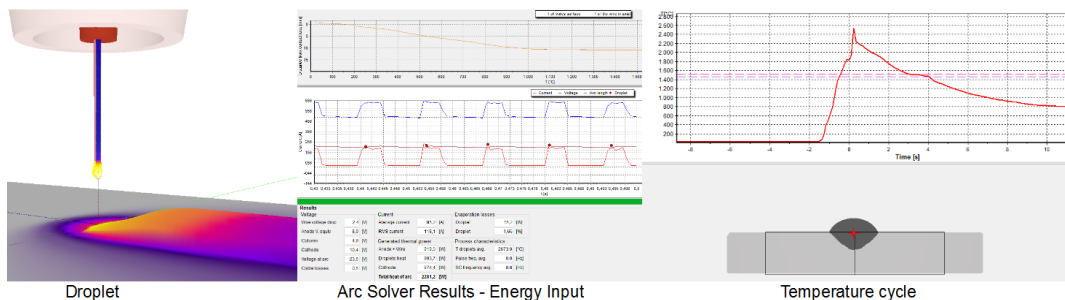
In the second step the user defines the travel speed and the length of the simulation task. The minimum simulation length to calculate the weld pool dimensions and the equivalent heat source is set automatically. SimWeld provides fine, medium and coarse mesh discretisation to balance simulation time and accuracy of results.

The last pre-processing task in SimWeld is the definition of the machine settings and process parameters (Fig. 5). SimWeld provides the non-pulsed process as well as the pulsed process with U/I and I/I modulation.



**Fig 5:** Machine Settings in SimWeld

The SimWeld simulation provides information about the droplet, the current and voltage distribution over time, discrete voltages between torch, work piece, the energy input by drop and the energy input of the arc (Fig. 6). This information is helpful for design engineers who are far apart from manufacturing places to estimate realistic machine settings. The temperature cycle of any point in the cross section is provided as well (Fig. 6 right).



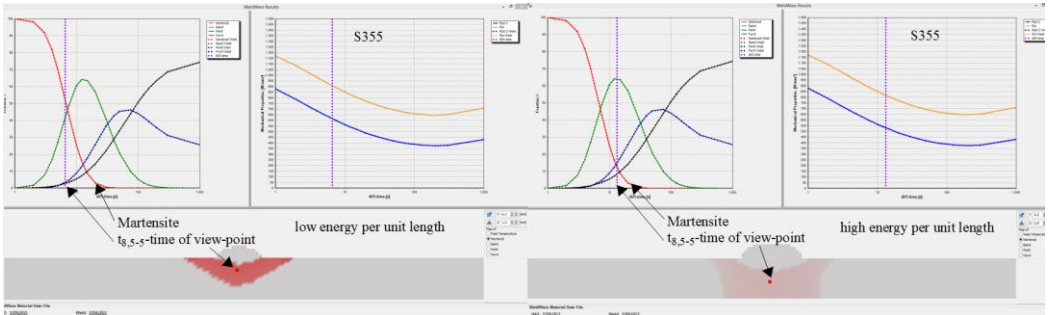
**Fig. 6:** SimWeld Results

The cooling rate needed to calculate microstructure and mechanical properties with WeldWare can be extracted from this temperature curve. As SimWeld provides this

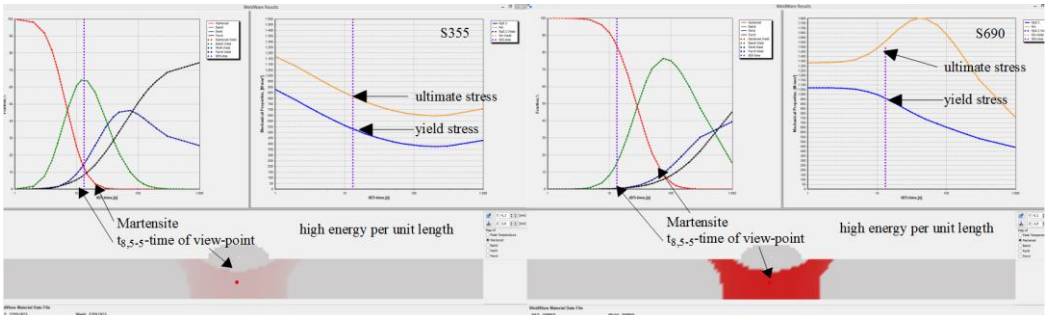
temperature curve within the whole cross section nearby the weld pool then distribution of phases and mechanical properties can be calculated for the whole cross section too.

### WELDWARE SIMWELD INTERFACE

The idea of the WeldWare®-SimWeld interface is to automate the manual calculation of microstructure and mechanical properties in WeldWare® for the thermal curves from SimWeld. The WeldWare® FEM-Interface exports the wwd-file. The wwd file is read by SimWeld. The extraction of thermal curves and the estimation of cooling times are done automatically via a discrete grid over the cross section. A flag is set to divide the area of molten zone, temperature exceeds melting temperature, the area of heat affected zone, temperature exceeds Ac3, and the area of the material unaffected due to microstructure transformation, temperature do not reach Ac1, which remains in the state of the base material.



**Fig. 7:** Martensit distribution for S355 (1.0570) left low right high energy per unit length.



**Fig. 8:** Martensite distribution and yield strength left for S355 (1.0570) right for S690 (1.8928)

The visualisation of the results provides an impressive overview of the structural situation of the weld. Critical conditions can be detected as the first step for improvement. In case of unfavourable condition the machine settings can be changed to improve the weld quality.

Fig 7 shows an example where the martensit proportion can be decreased by a change of welding parameter to obtain a higher energy per unit length.

The next example demonstrates the influence of different materials by same welding condition on the microstructure and on the yield strength (Fig 8).

## SUMMARY

The junction of WeldWare<sup>®</sup> and SimWeld closes the gap between metallurgical estimation of the state of the weld and the thermal engineering of the optimization of machine settings.

The WeldWare<sup>®</sup> - SimWeld interface provides to the welding engineer a tool that helps to check the quality of the weld concerning microstructure, mechanical properties as well as weld pool evolution and penetration. And it also helps to optimize unacceptable conditions either by a modification of weld parameters or by a modification of the material respective the chemical composition.

The last benefit is the check of the weld quality regarding the chemical composition of the delivered heat of the steel.

## REFERENCES

- [1] T. LOOSE ; A. RAUSCH ; F. HANEMAN ; A. SCHARFF: Ermittlung und Aufbereitung von Werkstoffdaten für die numerische Schweißstruktursimulation. *In: Tagungsband Sysweldforum 2011, Weimar.*