The Welding Simulation Solution from ESI GROUP

An Economic and Predictive Simulation Solution to Compute the Heat Effects of Welding

Courtesy WAGON Automotive GmbH

Dr. Frederic Boitout
Dr. Damian Dry
Yogendra Gooroochurn
Philippe Mourgue
Harald Porzner
1 INTRODUCTION

The welding process has always played a major role in industrial production, especially in the automotive, maritime, and aerospace industries. Despite many advantages, welding has some process-specific disadvantages: thermal expansion and shrinkage, micro structural transformations, stresses and component distortions develop. All, of which, need to be controlled. For simulation purposes, it is desirable that distortion and stresses of the component are calculated prior to, during and following the welding process, and that these factors are reduced by varying welding parameters, welding processes, sequence, position of welding seams, clamping conditions and the behavior of the microstructure.

Distortion, residual stresses, and plastic history of welded components can be calculated with the simulation software SYSWELD, taking into account all relevant physical phenomena. Therefore, the designer can specifically influence optimization of the welding process and component distortion.

In case of very large automotive and maritime structures, transient simulations are used for the computation of local models, for the local – global approach. Based on this methodology, ESI Group has developed a new product called Pam Assembly, which will be introduced in this paper.

2 SYSWELD Welding Process Evaluation

Welding of steel structures involves complex interactions between thermal, metallurgical, and mechanical phenomena leading to residual stresses and distortions, which can enhance the structure’s service life and can reduce significantly fabrication costs.

For distortion control, fabrication design via modeling can eliminate the need for expensive distortion corrections, reduce machining requirements, minimize capital equipment cost, improve quality, and permit pre-machining concepts to be used.

Residual stress control via modeling can reduce weight, maximize fatigue performance, lead to quality enhancements and minimize costly service problems.

SYSWELD and PAM ASSEMBLY are specifically developed for this purpose. It offers all existing Finite Element based methodologies and technologies to simulate welding fabrication. In this paper, these methodologies are briefly explained and discussed with respect to quality of computed results and costs.

3 SYSWELD Welding Multi-Physics Capabilities

The physical phenomena involved in welding processes, and their interactions, as integrated by SYSWELD are summarized in the following figure.
The SYSWELD solver provides an automatic solution for welding problems, covering all related complex mathematics and material physics. Depending on temperature, phases, and proportion of chemical elements, thermal, micro structural and mechanical results are computed, including:

- Latent heat effects of phase transformation and melting/solidification
- Changes in microstructure
- Diffusion and precipitation of chemical elements
- Isotropic, kinematic and mixed hardening including phase transformations
- Visco-plasticity including phase transformations
- Transformation plasticity
- Non-linear mixture rules for the yield stress of phases
- Phase dependent strain hardening
- Restoring of strain hardening during diffusion controlled phase transformations
- Removal of mechanical history when melting
- Automatic activation of mechanical history during solidification
- Material properties depending on temperature, phase proportions, and proportion of chemical elements
- All features dedicated to the methodology of finite elements.

It is important to note that the user does not need to be familiar with the solving mathematics in order to perform welding computations. Specific advisors help the user to prepare all input data needed for the solver engine and to set up a project. A limited knowledge of SYSWELD language is required because Welding and/or Assembly Advisor automatically produce all input data. The time needed to set up a Welding computation is thus drastically shortened.

4 SYSWELD Welding Solution for Transient Welding Processes Simulation

4.1 The Welding Advisor

SYSWELD is Finite Element software that simulates all usual welding processes like MIG-, TIG-, laser-, Electron beam welding. The aim of this procedure « Welding Advisor » is to simplify classical SYSWELD input data in order to create automatically from the input parameters all the input data and files necessary to the solution of a problem. It contents the Heat Source Fitting tool to adjust the parameters of all predefined heat sources implemented in SYSWELD. Using a material database, a power source database, a welding operation description, individual clamping conditions and a process driven set of numerical parameters, the Welding Wizard which is also a component of the Welding Advisor generates all solver files required to run transient (step-by-step) and steady-state (moving reference frame) welding simulations. This simulation can be achieved on solid, shell/solid and shell elements. The Welding Wizard can simulate mono-pass welding with or without weld deposit material as well as multi-pass welding, along arbitrary trajectories in space. The multi-pass welding joints can be treated sequentially or in parallel. In previous versions, multi-pass welding required a sequence of welding projects. A more advanced method is now available.
4.2 Multi Pass Welding

Multi Pass Welding Joints are very important part of steel constructions and pressure vessel components, because defect occurs very often in them. Residual tensile stresses have negative influence on the structure lifetime and its brittle fracture resistance. Residual stresses create balanced system of inner forces, which exists even under no external loading. The welding joints have to be designed and produced with care.

Due to the number of passes, which can be very important in case of multi pass welding, ESI group has developed an automatic tool in order to help the user for the management of such complex simulation. This tool, the Multi-pass advisor manages the computation in order to simplify the workload of the user. All welds involved in the multi-pass process are computed according to the same scheme initially defined in the Welding Wizard. When the project is saved the mesh is checked, updated and all input data for all welding simulation are created.

By using the check dialog box, after the selection of the welding project, the list of welding joint is proposed. The mesh that will be used for the computation of the selected joint is updated such as the standard ‘Check’ procedure can be used.
Figure 4: Tools for Multi-pass Welding

After the selection of the welding project, the Solve editor box is opened. The ‘solve as a single weld’ option allows to run the computation of the selected joint independently of all previous one. This option must be used for a checking purpose. The list of the joints to be computed must be selected before validation. For the whole simulation, all welds must be selected.

4.3 Spot Welding

Resistance spot welding is an efficient process to join vehicle body parts. This process involves strong interactions between electrical, thermal, metallurgical, and mechanical phenomena. With the coupling between electromagnetism, heat transfer, metallurgy, and mechanics, this process is accurately simulated with SYSWELD.

This numerical approach makes it also possible to account for the evolutions of the contact surfaces. The electro-thermal contact conditions are affected on a macroscopic scale by the evolution of the contact surfaces but also on a microscopic scale in the evolution of electro thermal contact resistances.

Figure 5: Comparison between numerical (Blue and Red line) and experimental nugget size at the end of heating

It is important to note that this simulation can be considered as a local model and repeated several time on a global model by using local global approach. The main interest is to analyze and optimize, with very short computation time, the welding sequences in order to reduce on the global distortion.
4.4 Friction Stir Welding,

Friction stir welding (FSW) is an emerging welding process, which was developed initially for aluminum alloys by TWI. This process involves strong interactions between thermal, metallurgical, and mechanical phenomena as shown in the following figure.

![Figure 6: Coupling between heat transfer, metallurgy and mechanics.](image)

In the FSW process, the heating is provided by the mechanical dissipation due to the strains and the contact conditions between the tool and the material.

In SYSWELD a three-dimensional model based on the Finite Element Method has been developed accounting for the thermal and the mechanical phenomena in a fully coupled approach. The stress equilibrium, the energy and the mass conservation are solved in an Eulerian frame for the stationary step of the process, considering an incompressible non-Newtonian fluid. The mechanical stresses are calculated from the velocity field and the thermal dissipation can be easily deduced.

![Figure 7: Temperature profile (°C) for a shear stress $\tau$ and Streamlines for a shear stress](image)
Figure 8: Velocity profiles (mm.s⁻¹) on upper surface for two values of the shear stress \(\tau\)

5 SYSWELD and PAM ASSEMBLY Simulation Solution for Large Structure

For very large structures as maritime and automotive structures, standard step by step welding methodologies cannot be used as far as these methods generate and require too important computations time and computer memory size.

In order to exceed this limitation without detriment to result quality, ESI Group proposes through SYSWELD and Pam Assembly software innovative solutions based on the Local Global methodology and on the Welding Macro Element technology.

The local global methodology is available in SYSWELD since 4 years via the Assembly Advisor tool. The latest technology called the WME has been implemented in a new product called PAM ASSEMBLY. It is a logical extension of the Finite Element Code SYSWELD.

This new technology offers new perspectives as the global computation is achieved on shell elements only instead of Shell/Solid or solid element. Consequently, only 2D elements are manipulated in order to create the global mesh and the computation time is strongly reduced due to the reduction of the number of degrees of freedom.

Pam Assembly has been developed in a new environment common to other products of ESI Group. All the common tools are available: The graphic user interface features, the preprocessor and the post processor.

Pam Assembly is above all an editor that allows defining, to prepare and to set up an assembly simulation based on the local global methodology and on the welding macro element technology.
It generates automatically all the input data required by SYSWELD to execute the simulation. Indeed SYSWELD remains the solver and it manages the calculation of the welding macro elements as well as the global computation of the distortions of the structure. It is important to note that the user does not need to be familiar with nonlinear Finite Element technology in order to use Pam Assembly.

Pam Assembly contains also an automatic meshing tool to create automatically the mesh of the seam weld and to prepare the finite element model needed for the solver.

Figure 10: Pam Assembly: Suspension Member Automotive Industry

Figure 11: Shipbuilding Structure

This new software with this new innovative WME technology is especially dedicated to decrease costly design errors. Pam Assembly allows user-defined weld sequencing; it helps to optimize part geometry, materials, and process parameters during the early stages of a new design cycle avoiding expensive engineering changes that could occur later.
Figure 12: The basic concept of Welding Assembly

Figure 13: Positioning of Pam-Assembly in your workflow
6 Welding User’s Guide

A Welding User’s guide has been added to the set of documentation. It covers the usage of the Welding Wizard as well as all the engineering knowledge related to steady state and transient welding. It includes the following chapters:

- Usage of the Welding Wizard
- Messages Managed by the Welding Wizard
- How to Choose Numerical Parameter Files
- Frequently Asked Questions
- Way to Work
- The Most Important Tips and Tricks
- Guidelines for Large Problems
- Guidelines for Transient Welding of Shells
- Advanced Welding Modeling
- Access to Electronic Manuals – Getting Info from Manuals
- Quick Checklist
- A Tutorial – Keys to Convergence
- Step by Step Example
- Systematical Example
- How to Present Results in an Effective Format
- Typical Postprocessing Results

Figure 14: Welding Users Guide
7 CONCLUSION

ESI Group offers an economic and predictive solution for welding and welding assembly. SYSWELD is especially dedicated for transient standard MIG-, TIG-, Laser-, Electron Beam welding simulation and no standard Spot-, Friction Stir welding simulation by taking into account all relevant thermal, metallurgical, and mechanical phenomena.

Pam Assembly is especially dedicated for assembly by welding processes of very large structure. It is based on the Local Global methodology and on the new innovative welding macro element technology. It allows you to perform very fast distortion due to welding assembly without having knowledge in nonlinear Finite Element methods.

8 How to Get Further Information

Further information about SYSWELD for Heat Treatment is available through all subsidiaries of the ESI Group or directly from the ESI Group web-page www.esi-group.com.

Or simply contact Harald Porzner, Harald.Porzner@esi-group.com