The Welding Simulation Solution

ESI GROUP

Courtesy WAGON Automotive GmbH
The Welding Simulation Solution

SUMMARY OF THE WELDING OFFER

ESI GROUP

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GETTING VALUE

INDUSTRIES OBJECTIVES

The Industries objectives are

- Market effectively
- Reduce costs
- Shorten time to market
- Reduce downtime
- Improve productivity
- Increase efficiency
- Improve profitability
- Gain access to new, global markets
- Enhance product quality and reliability
- Introduce innovation
- Reduce weight
- Reduce scrap and rework
- Avoid failure

The Welding Simulation Solution has been designed to get value with respect to the listed objectives, though computer modeling.

INDUSTRIES BENEFITS

Using ‘The Welding Simulation Solution’, you will be able to

- Minimize production cost
- Minimize structural weight
- Minimize distortions (distortion engineering)
- Minimize product risk in the earliest stage of the product development cycle
- Master assembly problems
- Ascertain the level & distribution of residual stresses
- Control and minimize hardness and grain size in the FZ and HAZ
Avoid cold cracks

‘The Welding Simulation Solution’ helps you to

- Improve the product design
- Identify better processes or materials
- Meet procedure approvals
- Meet product acceptance standards
- Implement new production methodologies
- Meet contract quality requirements

Your objective to provide the best product possible is achieved by simulation-based process design through

- Improved understanding of the effects that lead to distortions and residual stresses
- Subsequent optimisation of the product design and the manufacturing processes

A key feature of ‘The Welding Simulation Solution’ is the sensitivity analysis

- Major influence: A change in the parameter of 10% leads to a change of 100% in results
- Moderate influence: A change in the parameter of 10% leads to a change of 10% in results
- Low influence: A change in the parameter of 10% leads to a change of 1% in results

The sensitivity parameters studied are

- Welding process itself
- Welding process parameters
- Process stability (gap)
- Welding sequence
- Number and length of welding joints
- Position of welding joints
- Clamping conditions
- Design
- Material properties
- Material combinations
- Transformation behaviour of the material

**IMPROVEMENT OF THE PERFORMANCE AND QUALITY OF THE PRODUCT**

Controlling material characteristics via the computer can significantly enhance the performance and quality of a product. Controlling residual stress via the computer can significantly enhance the quality and structure’s service life.

Residual stress control via modeling can:
- Reduce weight
- Maximize fatigue performance
- Lead to quality enhancements
- Minimize costly service problems

“The Welding Simulation Solution” was specifically developed for this purpose. It offers all existing Finite Element based methodologies to control material characteristic and residual stress via the computer.
DISTORTION ENGINEERING – COST REDUCTION

Designing the welding fabrication via the computer to minimize or control distortion can significantly reduce fabrication costs.

Fabrication design via modeling can:

- Eliminate the need for expensive distortion corrections
- Reduce machining requirements
- Minimize capital equipment cost
- Improve quality
- Permit pre-machining concepts to be used
‘The Welding Simulation Solution’ was specifically developed for this purpose. It offers all existing Finite Element based methodologies to control welding fabrication via the computer.
POSITION IN THE PRODUCT CYCLE

‘The Welding Simulation Solution’ is placed at the earliest stage of the product cycle to

- Study distortion influencing parameters in
  - Material
  - Process
  - Design
- Take preventive measures for low-distortion welding constructions
- Avoid over-dimensioning

‘The Welding Simulation Solution’ is placed at the earliest stage of the product cycle to choose the best

- Welding process
- Type of welding joint
- Number and length of welding joints
- Sequence and welding direction
- Clamping conditions

‘The Welding Simulation Solution’ is placed at the earliest stage of the product cycle to

- Choose the best design dimensions regarding cost and weight
- Make the design decisions taken more safer
- Minimise post-design costs by avoiding failure or repair at a late stage of the product cycle
- Understand the physics which lead to distortions, residual stresses and failure during in-service behaviour
- Derive or improve design rules from sensitivity analysis
- Understand the differences between adjustment-specimen and real parts
- Improve established production processes
BENEFICIARIES

The beneficiaries are

- Producers of Welded mass production parts
  - High volume of Welding joints /day
  - Anybody using Welding robots
- Producers of mission critical parts (space mission equipment, power plants)
- Producers of expensive parts (turbines, power plants)

In Terms of Industry sectors

- Vehicle and Aerospace Industry
- Heavy Industry
- Nuclear Industry
- Chemical Industry
- Suppliers
- Universities and Research Institutes

These include:

- Product manufacturing
- Product design
- Durability evaluation
- Crash worthiness
- Structural behavior - protection of functionality
THE TEAM BEHIND ‘THE WELDING SIMULATION SOLUTION’

By choosing ‘The Welding Simulation Solution’, you will benefit from the experience of a team dedicated to welding and heat treatment simulation solutions. You will have access to more than 60 years of simulation engineering expertise.

The team behind ‘The Welding Simulation Solution’

- **Center of Excellence organization**
  - Dr. Frederic Boitout and team
  - Head Software development
  - Dr. Bruno Solcoumiac
  - Welding Assembly development
  - Dr. Yannick Vincent
  - Material expert
  - Philippe Mourgue and team
  - Head Consulting and QA
  - Harald Porzner
  - Product and business development management, head CoE

- **Scope**
  - Services and software solutions
  - More than 60 years of welding and heat treatment simulation expertise
REPRESENTATIVE REFERENCES

INDUSTRY

Air Liquide, ALCOA, AW Engineering, Bechtel Bettis, BIAS, BOSCH, CEA Saclay, CEA Valduc, Centro Sviluppo Materiali, CETIM, CNRC-NRC, Corus Technology BV, DaimlerChrysler AG, DENKI KOGYO, ELECTRIC BOAT, FHG IWM, FHG IWS, FRAMATOME, GKN, HITACHI, KENKI HYUNDAI, INA, India Ghandi Center for Atomic Research, JFE SYSTEMS, KAIST, KATECH, Knolls Atomic Power Laboratory, NISSAN, POSCO, Pratt & Whitney Aircraft, PSA, RENAULT, Rolls Royce, SAMSUNG, SERCO, SETVAL, SHANGHAI BOASTEEL, SOLLAC, SUZUKI, TOSHIBA, TOYOTA, UAM, VW, VZLU, ZF

UNIVERSITY AND INSTITUTES

Many Universities and Institutes around the World are using the Welding Simulation Solution of ESI for scientific purposes

GENERAL ESI GROUP
APPLICATIONS

TRANSIENT WELDING

“Using the finite element code SYSWELD at Fraunhofer Institute for Mechanics of Materials complex thermo-mechanical analyses of the resulting distortion and residual stresses due to the welding of aluminum structures have been performed. With the aid of heat sources which were especially developed for the weld bead of aluminum and adapted to the temperature field and macro-sections from experimental measurements an excellent agreement of calculated and measured distortion of an automotive construction was reached”

Dr. Dieter Siegele, Head of Department Safety and Availability of Components, Marcus Brand, Welding Mechanics, Fraunhofer Institute for Mechanics of Materials, IWM, Woehlerstr. 11, 79108 Freiburg, Germany.

Courtesy AUDI AG, FHG IWM
Best-estimate solutions for complex and laser-beam welded structures (3 welds)
Fraunhofer Institut for Mechanics and Materials at www.iwm.fraunhofer.de/englisch
Prof. Dr. Peter Gumbsch

Distortion Calculation testing, verification

Material zones:
- Weld-material
- Heat affected zone
- base-material
Full measured thermomechanical properties as a function of temperature, rate and strain-rate.

Displacements after welding of 3 welds, unclamping and cooling

- bending at two points

CONTOURS
- norm
- Time: 1000
- Deformed shape x 10
- Computed Reference Global
- Min = 1.00212e-030
- Max = 6.65960

Distortion measurements, courtesy Audi

Bending distortion in mm measurement | FE-calculation

3.95 | 3.92

Courtesy AUDI AG, FHG IWM

Power train – Distortion and stress engineering, weld quality

Experiment vs. simulation – temperature field

Distortion evolution with different process conditions

Courtesy VW AG
BMW 1-series, cross tube of front axle carrier, Courtesy BMW

Usage of a standard heat source

BMW 1-series, cross tube of front axle carrier, Courtesy BMW – Temperature field validation
Joining process – cast iron and gear steel

Case hardening of the gear

Distortion after welding - amplified

Simulation of:
- Case hardening of the gear
- Turning of the gear
- Press fitting on the cage
- Welding

Joining of a ‘Schweller’ Chaining with stamping simulation – Courtesy AUDI AG

Courtesy BMW
Welding of a rear axle wing – Courtesy BMW AG

Transient Welding of a door component – Courtesy WAGON Automotive GmbH
Transient MIG Welding of a B-Pillar-Roof connection – Courtesy AUDI AG

Transient Welding of an engine carrier – Courtesy VW / FHG IWM / WAGGON
Study of weld positioning variations – Courtesy UAM

Single pass welding of an aluminum rim modeled with solid models
Single pass welding of a steel rim modeled with shell elements

Chaining of forming and welding simulation – ESI example
Chaining welding and stamping simulation – extraction ESI Brochure

Definition of Problem

Initial Situation
The numerical computation of welding distortion within a production chain is not yet applied for industrial purposes.

Residual stresses and structural influences due to preliminary manufacturing processes may have a significant influence on the distortion results.

- Heat effects during the welding process
- Welding distortion and change of the state of the residual stresses
- Accuracy of sheet metal parts

Joining of stamping and welding simulation – Courtesy IWB
Method of resolution – Courtesy IWB

Laser beam welding task – Courtesy IWB
Final distortion after welding, unclamp and cool down

Measurements – solid model, shell mode without chaining, shell mode with chaining – Courtesy IWB
Rolls Royce validations - Courtesy Rolls Royce

Multi-pass Repair Welding in Nuclear Industry – Courtesy UAM (former Vitkovice)
Multi-pass Welding – Courtesy AREVA NP (Former FRAMATOME)
SYSWELD at Serco Assurance

Development, validation and application of residual stress prediction methodologies. These provide cost-effective assessments of multipass welds in thick-section components, such as those commonly found in the nuclear industry.

Multi-pass Welding – Courtesy SERCO

Experimental Validation – Transient Welding

Validation of transient welding simulation for Heavy Industry – Courtesy UAM
Validation of Welding of Aluminum profiles – Courtesy FORD / Jaguar

Good correlation with measured results

Validation of Welding of Aluminum profiles – Courtesy FORD / Jaguar
STEADY STATE WELDING

Welding of Aluminum Alloys - Aerospatiale

Courtesy Aerospatiale

1000 mm t-joint

30,600 nodes
Steady state welding

Steady state welding – ESI example
MACRO BEAD WELDING

Energy release in an exhaust system joint – Courtesy Renault

Macro bead welding and chaining with stamping simulation – ESI training example
Typical Heavy Industry Specimen – ESI training example
WELDING ASSEMBLY

“A very good agreement has been achieved between measurements and simulations”
Marek Slovacek, Ph.D, Head of the department Technology processes, Institute of the applied mechanics Brno, Ltd., Veveri 95, 611 00 Brno, Czech republic, about the Local-Global Approach

Validation of the local-global method for Heavy Industry – Courtesy UAM

The local-global method in Heavy Industry – Courtesy UAM and ANSALDO
Welding of a front axle carrier – Courtesy BMW AG

Welding Assembly of a chassis component – Courtesy Renault
Laser Welding – Courtesy Benteler

Simulation of distortion
MIG-welding of axle part

material: AlMg3Mn

Welding simulation of an axle component – Courtesy DaimlerChrysler
Simulation of distortion

Sysweld “local - global” approach:

local model: quasistationary with respect to moving welding head

calculation of: phase transformation

projection to global model: local strain along weld path

elastic deformation of global model due to local strain along weld path

=> drastic reduction of total computing time

but:

=> simplification requires experienced user

Welding simulation of an axle component – Courtesy DaimlerChrysler

Simulation and Validation

measured displacement welded with “solid” clamping

measured: \( \Delta x = -2.08 \text{ mm} \)

simulation: \( \Delta x = -2.18 \text{ mm} \)

measured: \( \Delta x = -2.42 \text{ mm} \)

\( \Delta x = -2.52 \text{ mm} \)

# after adjusting heat input and meshing

Welding simulation of an axle component – Courtesy DaimlerChrysler
Welding Assembly of a bumper – Courtesy GM

Welding Assembly and comparison with measurements – Courtesy Alcoa
Welding Assembly of stiffeners in ship building – Publication SHI HANPAM 2003

Welding Assembly in Heavy Industry
Welding of a large T-joint in Heavy Industry – ESI example

Welding of a large T-joint in Heavy Industry – ESI example
Stresses

Sigma XX
Sigma YY
Sigma ZZ

YY
ZZ (Welding direction)
XX

Global computation: Deformation profile

Deformation after welding process: Still clamped
Final Deformation after release of clamps

Welding of a large T-joint in Heavy Industry – ESI example
Welding of thick material in Heavy Industry – ESI example

Welding of thick material in Heavy Industry – ESI example
Chaining of Stamping and Welding Simulation – ESI example

FRICITION WELDING

Friction Welding – Courtesy DaimlerChrysler AG
**FRICION STIR WELDING**

The Local–Global Method applied in spot welding applications – ESI example

**SPOT WELDING**

The Local–Global Method applied in spot welding applications – ESI example
Spot welding – Courtesy CORUS

Spot welding simulation and validation
Spot welding simulation and validation

Experimental measurements

Spot welding simulation and validation
Experimental results – Contact interfaces

1. Inductive sensor (inductive sensor with broad range, 0 mm)
2. Electrode pedestal
3. Profilometer
4. Reference level for measurement

Electrode profile measurement
XES: uncoated (strong coupling calculation)
XSG: coated

Spot welding simulation and validation
Spot welding simulation and validation

Validation

Welding of a two 1.5mm thick uncoated sheet assembly
(a) experimental device (b) finite element model.

(a)  
(b)
Spot welding simulation and validation
Spot welding – Courtesy WMG

Chaining of welding and crash simulation
SCIENTIFIC WORK

WHAT DO THE EXPERTS SAY

"Using the finite element code SYSWELD at Fraunhofer Institute for Mechanics of Materials complex thermo-mechanical analyses of the resulting distortion and residual stresses due to the welding of aluminum structures have been performed. With the aid of heat sources which were especially developed for the weld bead of aluminum and adapted to the temperature field and macro-sections from experimental measurements an excellent agreement of calculated and measured distortion of an automotive construction was reached"

Dr. Dieter Siegele, Head of Department Safety and Availability of Components, Marcus Brand, Welding Mechanics, Fraunhofer Institute for Mechanics of Materials, IWM, Woehlerstr. 11, 79108 Freiburg, Germany.

"A very good agreement has been achieved between measurements and simulations"

Marek Slovacek, Ph.D, Head of the department Technology processes, Institute of the applied mechanics Brno, Ltd., Veveri 95, 611 00 Brno, Czech republic, about the Local-Global Approach

"SYSWELD has not only accompanied our scientific research, concerning the fundamental principals of welding distortion and residual stresses of structures, but also opened the way for considering complex 3-d components. Using either transient computation methods or reduced models helped to achieve excellent results concerning the structural behaviour of welded parts."

Dipl.-Ing. Loucas Papadakis, Fügetechnologien, Institut für Werkzeugmaschinen, und Betriebswissenschaften (iwb), TU München, Boltzmannstr. 15, 85748 Garching

"At the Institute for Machine Tools and Industrial Management iwb (Technische Universität München), SYSWELD is intensively used for more then 5 years. It is applied as a strong tool for detecting part specific properties, e.g. stresses and distortion, during and immediately after treating by welding in an early state of Product Life Cycle. We look upon this program favorable in the production of tomorrow due to the still unexploited possibilities of this program."

Dipl.-Ing. Sven Roeren, Fügetechnologien, Institut für Werkzeugmaschinen, und Betriebswissenschaften (iwb), TU München, Boltzmannstr. 15, 85748 Garching

"The Bremer Institut für angewandte Strahltechnik (BIAS) uses SYSWELD for the simulation of various welding processes and the calculation of welding distortions. One essential advantage of SYSWELD is the consideration of phase transformations which are important for residual stress calculation in laser heat treatment. SYSWELD has been approved itself as a very useful tool to estimate process parameters ahead of experiments whereby time and costs could be reduced."
Dipl.-Ing. Jörg Woitschig, BIAS, Bremer Institut für angewandte Strahltechnik, Abt. Werkstoffe und Modellierung

“In the very complex field of welding and heat treatments simulation, new methodologies are necessary in order to follow the severe industry demand of reliability and low time cost. Sysweld is a numerical code that with its own routines and implemented metallurgical laws taken from International literature, fully satisfy these requirements. A great work we have done to verify the reliability of welding simulation with Sysweld by comparing numerical and experimental results in terms of temperature history and residual stresses; very good agreements were found. Another key factor is the excellent technical and numerical support we have always found by the ESI-Group members.”

P. Ferro, F. Bonollo, A. Tiziani, DTG - University of Padova, Stradella S. Nicola 3 36100 Vicenza (Italy)

“The Finite-Element-Program Sysweld has a logically founded and well elaborated structure of program and organization of data. The language of input-files is easily understandable. The possibility of calculating of phase transformation, the possibility of defining moving heat sources by weld lines in a simple way, the possibility of defining arbitrary functions in the data input, the possibility of using different solution procedures, and many other helpful features making Sysweld an excellent tool for research, which is not only used for welding simulation.”

Dipl.-Ing. Tobias Loose, European Welding Engineer, Lehrstuhl für Stahlbau, Universität Karlsruhe (TH), Kaiserstraße 12, D-76131 Karlsruhe

“In our Institute of Manufacturing and Welding Technology we use the Finite-Element-Code SYSWELD for the modeling of welding residual stresses both in public and in industrial R&D projects. The SYSWELD Code has a good functionality and a high scientific level. The ESI working group is ever striving to inform the users how to do a good welding modeling, and it distributes regularly useful information among the users. The ESI presentations are an excellent tool in our Institute's lectures on Welding Simulation.”

Dr.rer.nat. U.Semmler, Chemnitz University of Technology, Institute of Manufacturing and Welding Technology Reichenhainer Str. 70, D-09126 Chemnitz

“The welding simulation is a large domain that covers from trivial to complex problems, where various phenomena take part and require interpretation. This fact is valid in the both fields – research and industry. In that context a proper simulation code should supply possibilities for free definition of physical and phenomenological models; possibilities for their coupling into complex analyses; abilities for creating routines as well as a suitable tool for presentation of the results. Definitively, SYSWELD successfully attain these requirements.”

N. Doynov, Dr.-Ing., Chair of Joining Technology, Technical University of Brandenburg, Cottbus, Germany
"The commercial FE-software Sysweld provides the means to model and analyze complexly transformations of structure for metallic materials, and steel in particular. Therefore, it is now possible to investigate welding and heat treatment in a realistic manner. We are not aware of any other commercial software, which provides the functionality to realize such investigations with the required complexity. Sysweld is a flexible software which allows for scientific investigations to facilitate research, as well as practical applications, such as the optimization of welding processes or the prediction of complex residual stress behaviors (states of residual stresses) in a variety of metallic materials. Sysweld was used in innovative research on welding processes with silica glass and has also shown excellent results. The application and partial improvement of the software forms a vital basis for our ability to do research and for the acceptance of our findings."

Prof. Dr.-Ing. habil. Frank Werner, Head of Department Steel Structures, Bauhaus-Universität Weimar, Marienstrasse 5, 99423 Weimar, Germany
APPLICATIONS

"At the Institute for Machine Tools and Industrial Management iwb (Technische Universität München), SYSWELD is intensively used for more than 5 years. It is applied as a strong tool for detecting part specific properties, e.g. stresses and distortion, during and immediately after treating by welding in an early state of Product Life Cycle. We look upon this program favorable in the production of tomorrow due to the still unexploited possibilities of this program."

Dipl.-Ing. Sven Roeren, Fügetechnologien, Institut für Werkzeugmaschinen, und Betriebswissenschaften (iwb), TU München, Boltzmannstr. 15, 85748 Garching

Scientific work at IWB – Courtesy IWB
Comparison with measurements – Aluminum welding – Courtesy SLV Munich
Laser Welding – INZAT

Laser Welding - INZAT
Scientific work at IWB – Courtesy IWB

Laser Cladding – Courtesy FHG IWS
Electron Beam Welding – Courtesy see slide
NUMERICAL SIMULATION OF TIG-DRESSING OF WELDED JOINTS

The TIG-dressing of weld transition allows for improving of the fatigue strength of a welded connection by reducing the sharpness of the notch possible. The melting influences the welding seam geometries, as well as existing structural conditions and residual stresses are significantly. Taking a butt joint as an example, the changes in the microstructure will be shown, namely as results of a FE-simulation.

The IFW Jena produced MAG-welded butt-joints made of high-strength fine-grained steel S990QL (plate thickness 15 mm) for demonstration and investigation of a TIG-dressing of the weld transition. The microstructure after the welding changes due to the renewed heat input and partial melting. As a result of a low heat input transformation from austenite mainly to martensite occurs.

TIG-Dressing – Courtesy University of Weimar

Laser beam welding of silica

The laser beam welding of silica represents an innovative alternative to traditional oxyacetylene welding. The application of this technology allows an economic bonding of silica components, which raises the standards of joint qualities to a new level.

In a research project, the Bauhaus-Universität Weimar analyzes the CO₂-laser beam welding of silica elements numerically and experimentally.

Laser beam welding of silica – Courtesy University of Weimar
Welding of Nickel based Superalloys – Courtesy University of Padova

Welding of Nickel based Superalloys – Courtesy University of Padova
Welding of Nickel based Superalloys – Courtesy University of Padova

Welding of Nickel based Superalloys – Courtesy University of Padova
Residual stresses

High residual stresses close to the ‘nail head’

Welding of Nickel based Superalloys – Courtesy University of Padova
Main Topics

Welding and surface technology
- Welding, e.g., Laser welding
- Surface Processing, e.g., Laser beam cladding

Materials and modelling
- Joining, e.g., Hybrid structures
- FE-Simulation, e.g., Thermal treatment

Optical metrology and testing
- Titanium
- Aluminium
- System design, e.g., Endoscopy sensor
- Non-destructive testing, e.g., Topography

Welding and surface technology – Courtesy BIAS

Simulation of laser heat treatment with SYSWELD
Development objective: Computation of internal stresses from laser heat treatment as input for fatigue limits calculations

Temperature
Stress after cooling

Welding and surface technology – Courtesy BIAS
Scientific work at BTU Cottbus

An external process model for weld pool simulation of the laser beam welding has been developed. This model considers all relevant physical phenomena that influence the shape of the weld pool, e.g., convection and Marangoni effect. The process model calculates furthermore the temperature field in a local domain inside and around the weld pool (Micro-model). The temperatures are transferred to the global FE-model (Macro-model) by chimera approach. A procedure in SYSWELD has been created for this purpose.

This procedure allows correction of the temperature field at every time step considering the temporary conditions, obtained from the mechanical response of the body, e.g., the gap opening during welding. It also involves simple parameters for adjusting the weld pool size and shape to experimental data.

Benefits:
- Improved precision of the calculated displacements due to precise description of the temperature field
- Simulation of laser beam welding, regarding the heat input variation after the gap opening

Laser Welding – Micro-Macro Model taking into account changes in the gap and fluid flow – Courtesy BTU Cottbus
Laser Welding – Micro-Macro Model – Courtesy BTU Cottbus
It is also possible to use simultaneously two or three different kinds of sources in order to simulate the correct fusion zone shape of the bead.

2D representation of thermal field (°C) in a cross section of the bead at time 0.32 s (the red zone correspond to the molten metal) and solidification temperature interval during the maximal extension of fusion zone (laser welding of AISI 904L stainless steel).

Fig. 4: Comparison of the measured and predicted thermal cycles on EBW of inconel 706 [37]
Phase proportions in Multi-Pass Welding – Courtesy University of Padova

Multi-pass welding – Courtesy Institute de Soudure
Welding simulation using advanced meshing techniques – Courtesy CNRS
Welding applications – Courtesy TU Olomouc

Welding applications – Courtesy TU Olomouc
Welding applications – Courtesy TU Olomouc

Simulation of hot cracking – University of Erlangen-Nürnberg
Viscoplastic behavior of steels during phase transformations

For low stress levels
- Transformation (visco)plasticity
  \[ E_{ij}^{\text{vp}} = - \frac{3 \Delta \varepsilon_{ij}^{\text{pl}}}{\sigma' + K_1 (E'_{ij})^m} \left( \frac{1}{g(z)} \right) S_0 (m z) \]

- Classical (visco)plasticity
  \[ E_{ij}^{\text{vp}} = \frac{3}{2} (1-z) \frac{1}{\sigma' + K_1 (E'_{ij})^m} \left( \frac{1}{g(z)} \right) S_0 \frac{z^{\text{eq}}}{z_{\text{eq}}} + \frac{3 (\alpha_1 - \alpha_2)}{\sigma' + K_2 (E'_{ij})^m} \left( \frac{1}{g(z)} \right) S_0^f \]

For high stress levels
- The equivalent stress is supposed to reach some ultimate stress
  \[ \Sigma_{\text{eq}}^{\text{eq}} = \Sigma^{\text{eq}} \]
  \[ \Sigma^{\text{eq}} = \left( \left( \frac{1}{\sigma'} \right) \right) \left( \sigma' + K_1 (E'_{ij})^m \right) \left( E'_{ij} \right)^{\text{eq}} + \left( \frac{1}{\sigma'} \right) \left( \sigma' + K_2 (E'_{ij})^m \right) \left( E'_{ij} \right)^{\text{eq}} \]
- Flow rule
  \[ E_{ij}^{\text{vp}} = \frac{3}{2} \frac{E^\infty}{\Sigma^{\text{eq}}} S_0 \]

Satoh Tests

Cycle 1
- Temperature (°C)
- Stress (MPa)
- Cycle 3
- Temperature (°C)
- Stress (MPa)

Cycle 2
- Temperature (°C)
- Stress (MPa)
- Cycle 4
- Temperature (°C)
- Stress (MPa)

Viscoplastic modeling – courtesy see slide
Laser Transmission Welding of Plastics

Welding of plastics – Courtesy Bayerisches Laserzentrum
AVAILABLE SOFTWARE TOOLS

MESHING – VISUAL MESH

Shell Meshing

ESI training example

Shell-Solid-Meshing

Courtesy “Automobilarbeitskreis”
Solid-Meshing

Courtesy AUDI AG

Automatic Shell Meshing

Automatic (Batch) meshing of WELDING ASSEMBLY components, based on user defined rules – ESI example
Automatic Link of Shell Components with Solid Welding Joints

For the purpose of Welding Assembly, global components meshed only with shell elements are linked with so-called Welding Macro Elements, which are a brand new development. Shell meshing is not time consuming and the components are linked automatically via Welding Macro Elements. The inner forces resulting from a transient or steady state welding simulation of a local model are then transferred to the Welding Macro Elements and the assembly simulation is performed.

![Automatic weld insertion in an Automotive part](image)

Automatic insertion of welding joints in shell meshed components - Courtesy RENAULT

How to Generate Quickly Meshes for Transient and Macro Step Welding Simulation

PAM-ASSEMBLY performs distortion simulation with a global mesh that consists of Welding Macro Elements and shell meshes of components. Temporarily, solid elements have been created to insert the Welding Macro Elements. Welding trajectories have been used to generate the temporary solid meshes by extrusion or block.

With VISUAL MESH, it is easily possible to generate from the generated meshes a shell only or shell-solid mesh for Classic Transient or Macro Step simulations. Only little organizational work is needed to generate the required meshes.
Generated shell-mesh in PAM-ASSEMBLY

With some further selective load of generated meshes, it is also easily possible to generate a shell-solid mesh.

Generated shell-solid mesh, meshes from a PAM-ASSEMBLY session merged in VISUAL MESH
Generated shell-solid mesh, meshes from a PAM-ASSEMBLY session merged in VISUAL MESH
TRANSIENT AND STEADY STATE WELDING

Welding Wizard

The Welding Wizard is an easy-to-use Graphical User Interface to facilitate the efficient set-up of welding simulations. No knowledge in Finite Element methods is needed to set up and run steady state and transient welding simulations. It combines a mesh, material data information from a material database, heat source information from a heat source database and individual process parameters in a way that input decks are created that can be automatically interpreted by the SYSWELD solver. The input decks consist of the definition of material properties, constraints and loads, and the command sequence for the solver.

Simulation set up with the Welding Advisor – The project set up is organized around one dialogue box

The Welding Wizard dialogue box
Local Model Wizard

The Local Model Wizard is a tool to set up automatically - based on practical process parameters only - rotational and translational T-, Butt-, and Overlap joints as well as welding joints based on a custom defined cross-section. The Local Model Wizard can be used either to quickly perform welding simulations of basic welding specimen for arbitrary purposes or as a tool to fill a local model database for PAM-ASSEMBLY. No knowledge in nonlinear Finite Element methods is required to use this tool.

The Local Model Wizard

The Local Model Wizard – Predefined local models
**Heat Source Fitting Tool**

The calibration of the heat transfer into the structure is one of the most important tasks in a welding (assembly) simulation. To check the process feasibility is however not the task of the engineer in this context – welding assembly simulation means computation of the heat effects of welding rather then process feasibility simulation. Consequently – for the purpose of the computation of the heat effects of welding - welding joints can be assumed that can be manufactured under valid process conditions, as for example described in American, Japanese or European norms. The task of the heat source fitting tool is to find - based on a heat transfer model - process parameters in a way that valid joints are produced. A fine tuning can be done based on micrographs and temperature and hardness measurements. Four joint profiles are predefined to fit the heat source: T, Butt, Overlap and User Defined. An automatic post-processing provides you with the most important results. The calibrated heat source can be stored in a database and used later for arbitrary purposes.

The Heat Source Fitting tool
**Hardness Simulation Wizard**

For any project set up with the Welding or Heat Treatment Wizard it is now possible to compute the hardness out of an easy to use dialogue box. The chemical composition is taken directly from the material database or can be entered by hand if not yet present. The hardness computation has been enhanced to high carbon contents above 0.5%.

The Hardness Simulation Wizard
Metallurgical Parameters Fitting Tool

It helps to fit the metallurgical parameters of phase transformations during welding. CCT diagrams as well as phase transformations during heating are calibrated with this tool.

CCT diagram fitting and automatic plotting
Multi-Pass Welding

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

ESI group has developed a multi-pass Wizard that helps the user to manage multi-pass welding. It simplifies significantly 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.

Tools for Multi-pass Welding

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.

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.
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.

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.

A Spot Welding Wizard has been developed to simplify the set up of spot welding simulations

Workflow of the Spot Welding Wizard
Workflow of the Spot Welding Wizard

Workflow of the Spot Welding Wizard
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.

Coupling between heat transfer, metallurgy and mechanics

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.

Temperature profile (°C) for a shear stress $\tau$ and streamlines for a shear stress
Welding Material Databases

The welding solution from ESI comes with a database that incorporates the most commonly used materials in the Industry.

The material data can be managed in Microsoft Excel®. A Macro exists which exports material data in the SYSWELD database format.

Phase transformation and melting enthalpy

Material data management in Microsoft Excel®
Check Box

The check box is a tool to check simulation projects that have been set up with the Welding Wizard. All necessary checks are available through one dialogue box.

Check of the Weld-line

Check of the heat exchange with the surroundings
Check of the heat transfer to the surroundings as a function of the temperature

Check of the power input
Check of the applied power density

Check of material groups
Check of the clamping conditions

Check of material properties
MACRO STEP WELDING

The Macro Bead Advisor

This is an easy-to-use Graphical User Interface to facilitate the efficient set-up of Welding simulations with the Macro Bead Deposit Method. It allows you to simulate the heat transfer into the structure in macro time steps, which vastly reduces the computation time for transient welding simulations. You can now simulate parts like suspension systems - or ship block components in a transient manner, within a reasonable time range.

The energy per unit length of weld is released in macro steps

Release of energy in macro time steps
WELDING ASSEMBLY

The Assembly Advisor

This is an easy-to-use Graphical User Interface to facilitate the efficient set-up of Welding Assembly simulations. The Welding Assembly Advisor opens a huge simulation application field – distortion control of large maritime and automotive structures with a reasonable amount of computer memory and computation of results within a extremely short time range.

The Welding Assembly Advisor was the first tool that enabled to use the local-global method for the simulation of Welding Assembly. Starting from 2006, PAM-ASSEMBLY is available for the set up of Welding Assembly simulations. The Welding Assembly Advisor in SYSWELD will remain; It allows the definition of very complex simulations, which require sometimes an advanced knowledge in the method of Finite Elements.
PAM-ASSEMBLY Database Manager

This is a tool to manage local models to be used by PAM-ASSEMBLY and computed with SYSWELD. It has been designed within SYSWELD to fill a local model database for PAM-ASSEMBLY with results computed with the help of the Local Model Advisor.

Export of local models in SYSWELD

Import of local models in PAM-ASSEMBLY
PAM-ASSEMBLY is a new integrated solution for the simulation of Welding Assembly. The main purpose of this tool is to compute the displacements after each step of an assembly sequence and unclamping. Using PAM-ASSEMBLY, the user is able to optimize, compare and finally select the best possible welding sequence and choice of clamping tools.

In PAM-ASSEMBLY, the Local-Global method is applied to simulate the effects of Welding Assembly. It is the most efficient method for large assembly designs.

PAM-ASSEMBLY graphical user interface
TOOLBOX CD-ROM

It contains Tutorials, User’s Guides, and the Engineering Guide. It enables engineers to understand and solve welding simulation problems.

ENGINEERING GUIDE

It covers all the background knowledge needed to work straight forward on heat treatment and welding problems.

EXAMPLES CD-ROM

It covers the major applications in Heat Treatment and Welding (Release in April 2006)
The Welding User’s guide covers the usage of the Welding Wizard as well as all the engineering knowledge related to steady state and transient welding.
KNOWLEDGE INCLUDED

- 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
KEY TECHNOLOGY

SIMULATED PHYSICS

SYSWELD simulates all the physics involved in heat treatment and welding, without limitation. Download an extensive paper from the ESI GROUP Web-page for details.

Illustration of the coupling of physics in SYSWELD

MOVEMENT OF HEAT SOURCES ALONG WELDLINES

Weld-lines and reference lines allow the arbitrary movement of welding heat sources in space. They are additionally used for many display and check purposes (power input along weld-lines for example) and to manage the time stepping for the solution.

Principles of the definition of weld-lines
REMOVAL OF MATERIAL HISTORY

SYSWELD is the only commercial Finite Element code in the market that masters the removal of the material history in case a defined temperature is exceeded. This feature is mandatory to reach the required high precision in transient welding simulations, in combination with unmatched computation speed and convergence behavior.

Phase transformations and removal of the material history

The welding heat source is moving along the weld path. Due to thermal gradients, plastic strains are built up in front and beside the heat source. In case the temperature exceeds a certain value, the material history is fully automatically removed. This is the reality.
MATERIAL PROPERTIES DEPENDING ON PHASES OR MATERIAL STATUS

All material properties can depend on temperature and phases.

Thermal conductivity depending on phases

Yield stress depending on phases
VOLUME CHANGES DURING PHASE TRANSFORMATIONS

Volume changes during phase transformations and all related mechanical phenomena like for example transformation plasticity are taken into account.

Dilatometer Tests

Control of the Thermal and Mechanical load.

Dilatometer test

Dilatometer Curve

- Thermal Strain: $\varepsilon_T^T(T)$, $\varepsilon_T^P(T)$
Change of volume during martensite transformation

Kinetic of Transformation
- Kinetic of Transformation: Martensite
- Low alloy Carbon Manganese Steel

Dilatometer Curve / Kinetic of Transformation
- Kinetic of Transformation: Bainite & Martensitique

Kinetic of phase transformations
PHASE TRANSFORMATIONS OF HARDENABLE STEEL

Isothermal and continuous phase transformations of hardenable steel are taken into account.

CCT diagram of hardenable steel

Simulated phase transformations
ALMGMN – KINETICS OF RECRYSTALLIZATION

The hardening due to mechanical treatment and the loss of hardening due to the heat effects of welding is treated in welding simulations.
ALMGSI – KINETICS OF PRECIPITATES

The precipitation hardening and the loss of hardening due to the heat effects of welding is treated in welding simulations.

Loss of strength due to dissolution of precipitations

DEDICATED MECHANICAL MATERIAL LAWS

All mechanical phenomena that occur in a welding process are accurately simulated.

Mechanical Model

- In SYSWELD, the total strain rate is partitioned as follows:

\[ \dot{\varepsilon} = \dot{\varepsilon}_e + \dot{\varepsilon}_p + \dot{\varepsilon}_{ip} + \dot{\varepsilon}_{th} \]

- Total Strain Rate
- Elastic Strain Rate
- Plastic or Visco-Plastic Strain Rate
- Thermal and Metallurgical Strain Rate
- Transformation Ploicity

Implemented mechanical models
Implemented hardening laws

The plastic behaviour model of steel during transformation presented above has been extended to take into account the viscous-plastic phenomena. They are introduced by making the yield stress of the phases depending on the rate of plastic deformation. The numerical implementation allows that elastic - plastic and elastic – viscous-plastic behaviors can be combined. The resulting model proposes a strain hardening both in additive and multiplicative form.

Viscous Plastic Model

- Each phase $i$ can present a viscousplastic behavior of the following type:

$$
\dot{\varepsilon}_i^{\text{eff}} = \frac{\sigma_i^{\text{eff}} - k_i(T, \varepsilon_i^{\text{eff}})}{K_i (\varepsilon_i^{\text{eff}})^m}
$$

Additive strain hardening

$$
\varepsilon_i^{\text{eff}}
$$

Multiplicative strain hardening

- $\dot{\varepsilon}_i^{\text{eff}}$ Equivalent viscoplastic strain rate (microscopic) of phase $i$,
- $\varepsilon_i^{\text{eff}}$ Strain-hardening scalar parameter (effective plastic deformation of phase $i$),
- $k_i(T, \varepsilon_i^{\text{eff}})$ Yield stress possibly function of the temperature and/or the strain-hardening parameter in the case of an additive isotropic strain hardening
- $m, n$ Hardening coefficient, Hardening Exponent, Strain rate sensitivity exponent

Viscous plastic model
MESH INDEPENDENT APPLICATION OF PROPERTIES

In fact, metallurgical laws are the basis of a drastically reduction of the time needed to set up a welding model. All material properties are applied independent of the mesh, depending only on the evolution of temperature and phase transformations or changes in the material status.

CHEWING GUM METHOD FOR FILLER MATERIAL

The modeling of filler material requires no specific user interaction beside the definition of the filler zone in the mesh. The addition of the material is managed through a specific metallurgical law, which transfers material having properties close to chewing gum to molten material, above a user defined temperature. More complex FEM techniques like birth and death are not needed.
CLASSIC FEM TOOLS

All kind of classic Finite Element tools like external loads, clamping conditions, etc. are available.

FULLY AUTOMATIC SOLVER

All the key technology as presented in this chapter is included in a transient welding simulation. Nevertheless, the solution process requires not any user interaction and is fully automatic. Not any knowledge in numerical mathematics is needed to set up and run a welding simulation.

NUMERICAL STABILITY
The numerical stability of SYSWELD is unmatched. Despite the fact that all the complex physics is simulated, the maximum possible time step can be applied without numerical problems. Consequently, you can run SYSWELD always with the maximum possible simulation speed.

Automatic management of the filler material along the moving heat source

**LINEAR SYSTEM OF EQUATIONS SOLVERS**

Direct optimized sparse and a highly optimized iterative solver are available for the solution of the linear system of equations.

**HARDWARE PLATFORMS**

SYSWELD is running on recent Windows, Linux and Unix computers.
SUMMARY – TECHNICAL FEATURES AND KEY TECHNOLOGY

- Movement of welding heat sources along arbitrary path in space
- Automatic and mesh independent calibration of the heat transferred into the structure along the weld path
- Phase transformation and melting enthalpy
- Phase and material status dependent material properties
- Fully automatic treatment of removal and birth of material history
- Fully automatic and mesh independent application of material properties depending on temperature and phases
- Fully automatic treatment of yet to be deposited material
- Nonlinear mixture rules for phase properties
- Restoring of strain hardening during transformation
- Dedicated integration of plasticity laws
- Nonlinear geometry (large strains and large displacements/rotations)
- Consistent tangent material matrix for isotropic, kinematic and mixed hardening, including phase transformations
- An iterative linear system of equation solver allows the treatment of very large structures on PC’s
- Generalized plane to plane contact
- Linear and parabolic solid elements, linear solid elements with incompatible modes, linear and parabolic shell elements
- Shell-solid models
- Welding dedicated numerical tools
- Welding simulation tools for all kinds of Industry and all kinds of metallic material
ILLUSTRATION – TECHNICAL FEATURES AND KEY TECHNOLOGY

Temperature field

- Melting occurs above 1500°C (red)

Filler material modeling

- The filler material is in this case modeled as an artificial phase with artificial material properties (not yet deposited material)
- Instantly above melting temperature, it transfers automatically to molten material
Simultaneous systematical comparison of the removal of the mechanical history and the temperature field in JASC Animation Shop®

Simulation of phase transformations
Residual stresses – hardenable steel

Residual stresses – non hardenable steel

- Same structural and process parameters
- Same scaling of results
Cumulated plastic strains alpha - phases - end

- Plastic strains that occurred in the alpha phase during heating
- Restoring of strain hardening during phase transformation was active for ALL phase transformations during cooling

The maximum temperature has been austenitisation temperature

Final yield stress distribution

- The final yield stress is a function of the composition of the phases and the strain hardening
Residual stresses after tempering

- Several hours tempering above 500°C
- Tensile stresses reduced
- Same scaling

Change of process conditions and wall thickness

- Heat affected zone smaller
- Stiffness reduced - stress level more similar to the 2mm loose clamped case
- 2m/min
- 1.2mm wall thickness
- Rigid clamping
- Energy density and cooling rates much higher

Tensile stress peaks
CHAINING WITH STAMPING AND CRASH SIMULATION

CHAINING STAMPING AND WELDING

The basic goal of distortion engineering

Chaining of stamping and welding simulation
CHAINING WELDING AND STAMPING

Chaining of welding and stamping simulation – Courtesy AUDI AG

CHAINING WELDING AND CRASH

Chaining of welding and crash simulation
An interface exists to transfer results from the Simulation World of Metallurgy to the Simulation World without Metallurgy.
WELDING-ASSEMBLY OF LARGE STRUCTURES

OVERVIEW

PAM-ASSEMBLY is a new integrated solution for the simulation of Welding Assembly of large structures. The main purpose of this tool is to compute the displacements after each step of an assembly sequence and unclamping. Using PAM-ASSEMBLY, the user is able to optimize, compare and finally select the best possible welding sequence and choice of clamping tools.

In PAM-ASSEMBLY, the Local-Global method is applied to simulate the effects of Welding Assembly. It is the most efficient method for large assembly designs.

General view of the Pam-Assembly Graphical User Interface
BASIC CONCEPT

**SYSWELD**
- Generation of local models
- Fully transient welding simulation of components including all physics
- Basic knowledge in physics and FEM required

**PAM-ASSEMBLY**
- No transient welding simulation – usage of local models
  - Continuous welding
  - Spot welding
  - Cold joining
- Components and larger assemblies
- Easy to use – no FEM knowledge needed
PAM-ASSEMBLY serves as an easy-to-use front end to perform Welding Assembly simulations for large structures. The physics of welding is not ignored – it is fully treated in the local models, which are simulated with the SYSWELD software. The basic idea behind the Local-Global method implemented in PAM-ASSEMBLY is to provide precision in Advanced Manufacturing simulation – without simplification of the physics of welding on the one hand, but very easy to use and very efficient with respect to computation time - even for large assemblies – on the other hand.

In PAM-ASSEMBLY, global components meshed only with shell elements are linked with so-called Welding Macro Elements, which are a brand new development. Shell meshing is not time consuming and the components are linked automatically via Welding Macro Elements. The results of a transient or steady state welding simulation on a local model are then transferred to the Welding Macro Elements and the assembly simulation is performed.

For the user, the manipulation of PAM-ASSEMBLY is simple: Only the meshed components, weld-lines that represent the position and direction of welding seams, and the computed results of a local model (accessible through a database) must be provided. After having defined clamping conditions and a welding sequence, a linear elastic analysis is performed to compute the distortion due to the Welding Assembly process.

Consequently, the user of PAM-ASSEMBLY need not be familiar with non-linear Finite Element simulations. All the complex physics is only used to generate the local model. This concept allows designers and manufacturing practitioners to quickly simulate distortion due to the heat effects of welding, without getting involved in non-linear Finite Element issues or numerical methods.

The local models are created in SYSWELD as required, with an automatic local model generator, or they can be selected from a local model database, which can be generated off-line. As a consulting service, ESI can provide extended local model databases, which are appropriate to individual company needs.

Thermal cycles, phase transformations, changes in material status, stresses, plastic strains, thermal strains, yield stress of the newly formed material and all other results related to a transient welding simulation are available for the local model.

This method to simulate welding assembly has been validated for more than five years with many Industrial partners.
POSITIONING IN THE PRODUCT AND PROCESS WORKFLOW

Solution positioning: Product and technology development

- Product Development
  - Concept
  - Construction
- Product Simulation
  - Stiffness
  - Fatigue
  - Crash
  - NVH
- Manufacturing
  - Joining
  - Process parameter
  - Permissible variation
  - Clamping tools
  - Distortion
  - Residual Stress
  - Strength

Solution positioning: From first design to the prototype

- Pre-Development
- Production-Development
- Component Design
- Manufacturing Concept
- Welding Simulation
- Welding tests
  - Optimization
- Local Model Database
- Welding Process
- Material
- Simulation
- Component tests
- Prototype
SYSWELD AND PAM-ASSEMBLY - SIMULATION SOLUTION FOR WELDING ASSEMBLY

For very large structures, such as maritime and automotive structures, standard step-by-step welding methodologies are not feasible since these methods require significant computation time and computer memory size.

In order to overcome this limitation without detriment to result quality, ESI Group has devised an innovative solution based on the Local-Global methodology and on the Welding Macro Element (WME) technology. The Local-Global methodology has been available in SYSWELD for four years via the Assembly Advisor tool. The WME technology has been implemented in a new product called PAM-ASSEMBLY. This new generation product is a logical extension of the Finite Element Code SYSWELD.

Historical Evolution

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

PAM-ASSEMBLY is developed in a new user environment common to PAM-STAMP 2G. All related user-friendly tools are therefore available: the graphic features, the pre-processor and the post processor.

PAM-ASSEMBLY is above all an editor that allows the user to define, prepare and set-up an assembly simulation based on the Local-Global methodology and on the WME technology. It automatically generates all the input data required by SYSWELD to execute the simulation. PAM-ASSEMBLY uses the SYSWELD solver to manage the calculations on the Welding Macro Elements, as well as the global computation of the structural distortions. It is important to note that the user does not need to be familiar with SYSWELD in order to perform a PAM-ASSEMBLY simulation.

PAM-ASSEMBLY also contains an automatic meshing tool to create the mesh of the seam weld and to prepare the finite element model required for the solver.
This new software with its innovative WME technology is specially dedicated to decreasing costly design errors. PAM-ASSEMBLY allows user-defined weld sequencing and facilitates the optimization of part geometry, material parameters and process parameters during the early stages of a new design cycle, avoiding expensive engineering changes that could occur later.
A TYPICAL WORKFLOW

The following illustrates the basic workflow of a Welding Assembly simulation. A systematic and complete example is provided with PAM-ASSEMBLY.

Assembly Workflow

- Simulation of the local models
  - Guided generation of an Advisor project for local models with the local model editor
  - Advisor guided simulation of the local model
- Export in a local model database
- Definition and simulation of the Assembly in PAM-ASSEMBLY

Local Model Editor: 2D Mesh Parameters
Local Model Editor: 3D Mesh Parameters

- Combination of predefined and custom clamping conditions is defined using groups created by the LME.
Import of Local Data in PAM-ASSEMBLY: Local Model A

Assembly simulation - Overview
Data Setup – Example: Properties of Joint W1

Data Setup – Example: Properties of clamp Beam_CL1
Sequence Manager:
Definition of Sequence

Following table sums up, how the welding sequence is defined:

<table>
<thead>
<tr>
<th>Step name</th>
<th>Deposited joints</th>
<th>Applied clamps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step1</td>
<td>W1</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step2</td>
<td>W2</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step3</td>
<td>W3</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step4</td>
<td>W4</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step5</td>
<td>W5</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step6</td>
<td>W6</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step7</td>
<td>W7</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step8</td>
<td>W8</td>
<td>Cl_Beam, Cl_Bracket, Cl_Bumper</td>
</tr>
<tr>
<td>Step0=Release</td>
<td>-</td>
<td>Free_N1, Free_N2, Free_N3</td>
</tr>
</tbody>
</table>

Sequence Manager – Example: Definition of Step1 and Step9_Release

© ESI GROUP
Results – Step 5 to Step 8

Results – Release Step
ESI Group is a pioneer and world-leading provider of digital simulation software for product prototyping and manufacturing processes that take into account the physics of materials.

Founded in 1973 by four Berkeley Ph.D. graduates, ESI Group now occupies a unique position in the high-potential Product Lifecycle Management (PLM) market.

ESI Group has developed an entire suite of coherent, industry-oriented solutions to realistically simulate a product’s behaviour during testing, to fine tune the manufacturing processes in synergy with the desired product performance, and to evaluate the impact of the environment on product usage.

Drastically reducing costs and development lead times, ESI Group has integrated into its global “Virtual Try-Out Space” (VTOS) offer major competitive advantages by progressively eliminating the need for physical prototypes during the product development phase.

With the collaboration of nearly 500 high-level specialists worldwide, the company and its global network of agents provide direct sales and technical support to customers in more than 30 countries.

The development of ESI Group is based on continuous innovation; this has earned the Group the qualification “innovative company” by the French National Research Agency, Anvar.
Expert in Virtual Testing

- Editor (ISV) of Applied Mechanics industrial software, providing decision-making solutions through virtual testing applications
- Expert in the field of physics of materials
- A FY-2004 turnover of 58,3 M€ with 80% outside of France
- Listed in Eurolist compartment C of Euronext Paris - NextEconomy (July 2000)
- Active player in market consolidation for ‘Virtual Prototyping & Simulation’ (MCAE)

Unique contribution to the ‘PLM’: Physics of materials

- Product performance
- Manufacturing processes
- Environment & usability
High Value-Added Engineering Services

Consulting services
- 30 years experience in consulting and R&D for defence, aeronautics, energy and transportation industries
- Centers of Excellence in key analysis fields: aerodynamics, casting, crash & occupant safety, biomechanics, material rupture, stamping, vibro-acoustics, metallurgy
- Full-mastering of project, integration of client-specific developments, on-site contracting

Training and assistance
- Hot-line and technical support ensured locally by the subsidiaries worldwide
- Training sessions and workshops for optimal use of software products

Industrial Sector Offering

Transportation:

Manufacturing Industries / Energy:

Electronics, Defence, Aerospace:
Solutions for Transportation (Automotive, Railways, Aerospace)

- **Body-in-white**: simulation of manufacturing processes: stamping, casting and welding of a vehicle body.
- **Body-with-trim**: simulation of crashworthiness and passenger passive safety in the vehicle interior.
- **Comfort, noise and vibrations**: simulation of acoustics and thermal comfort of a vehicle.
- **Engine and power train**: suspension systems, dynamics and performance.
- **Interactions of the vehicle with its environment**: (air, water, electromagnetic waves, biofidelic human)

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Worldwide Coverage

**Headcount**

- **500 specialists**
  (31 Jan. 2005)

- **12 subsidiaries**

- **33 agents**
ESI GROUP CONSULTING SERVICES

COMMITTING TO CUSTOMERS

Since more than 30 years, the interest of our clients is the center of our work, whether we are providing software, support or services. Over several decades, our clients have experienced us as experts in our field. We are at any time at your disposal to improve product performance and productivity on the one hand and shortening development times and cost on the other hand.

Consulting services are performed by highly skilled engineers, who, thanks to their in-depth engineering knowledge and their process understanding, are ready to team with you to help you to adopt an integrated innovation approach.

SERVICE OFFER - WELDING

*ESI Group offers support of customers and services in all engineering fields involving the following tasks*

- Development of innovative new welded designs and welding processes
- Improvement of the performance and quality of welded products
- Cost reduction of all welding fabrication processes
- Distortion engineering

*These tasks can involve the following welding processes and materials*

- Single pass welding, all kind of processes and materials
- Multi-pass welding, all kind of processes and materials
- Spot welding, all kind of materials
- Friction welding, all kind of materials
- Friction stir welding, all kind of metallic materials

You will find a good selection of our service portfolio in the chapters ‘Applications’ and ‘Scientific Applications’ of this document.

Do not hesitate to contact a subsidiary of ESI Group in your area. You will find the contact data either on the back cover of this document or at www.esi-group.com.

We look forward to working with you soon!
TRAINING COURSES

ESI Group Learning Solutions
2006
ESI GROUP LEARNING SOLUTIONS

Reliable, Flexible and Efficient Learning Programs

ESI Group has over 30 years of expertise in software application training courses.

These classes are taught by highly skilled engineers responsible for consulting and support activities, who, thanks to their years of practice and field experience, are fully prepared to answer to the participants’ needs.

For optimal knowledge transfer, ESI Group honours the following criteria, underlining the effectiveness of its learning programs:

- class sizes are kept small to ensure adequate attention for all attendees,
- time is set aside to work on each participant’s particular demands,
- training manuals and a computer are provided for each attendee,
- demonstrations and practical exercises are carried out throughout the training,
- ...

Participants come away from these classes with a good understanding of all the features of the ESI software of their choice as well as targeted knowledge for immediate application. The courses also provide an excellent forum for ESI Group customers to work with each other and share their experience in digital simulation.

From introductory to advanced or specialized sessions, ESI Group offers an expansive educational program.

In addition to standard courses, ESI Group can set up a dedicated learning program tailored to your needs and knowledge of the software, with flexible training times, content and duration. Customized courses take place either at one of ESI Group’s worldwide learning facilities or on-site, at your facility.

With decades of training experience and a proven educational methodology, ESI Group software learning courses are the best way to learn about the features and capabilities of the software products you work with daily.

We look forward to working with you soon!
WORLDWIDE LEARNING CENTERS

A broad and expert training network

With field subsidiaries and regional technical support offices spanning four continents, ESI Group provides personalized training services and high-level support to its customers worldwide.
MESHING WELDING APPLICATIONS

Reference: SWD-2005-WM-B
Level: Basic
Duration: 2 days
Audience: Engineers in product development, process design, and manufacturing dealing with welding processes, from Automotive and Heavy Industry
Objectives: Understand how to make the best possible meshes for welding simulation
Prerequisites: Required: engineering background with focus on welding engineering; strong understanding of practical welding. Helpful: basic knowledge of the Finite Element method.
Description: The art of meshing welding applications is the major subject of this course. Participants learn to mesh effectively two-dimensional and three-dimensional heat-treated structures.

Course content:
- Basics
  - Finite Element recommendations
  - Welding recommendations
- Meshing two-dimensional structures
  - Best practice
- Meshing three-dimensional solid, shell-solid, and shell structures
  - Best practice

Suggested next course: Welding Simulation Engineering – Getting it Right (SWD-2005-W-B)
WELDING SIMULATION - GETTING IT RIGHT

Reference: SWD-2005-W-B
Level: Basic
Duration: 3 days
Audience: Engineers from product development, process design and manufacturing dealing with welding processes, from Automotive and Heavy Industry.

Objectives: Understand the art of modeling for welding. Then, set up, run and interpret results of a welding simulation.

Prerequisites: Necessary: engineering background with focus on welding engineering and a strong understanding of practical welding.
Helpful: basic knowledge of the Finite Element method.

Description: The art of modeling for welding is the major subject of this course. The focus is on simplicity and productivity. Participants learn to simulate the heat effects of welding – i.e. distortion and residual stresses – in order to predict and minimize part distortions and improve durability. Improvement of processes and designs based on a deeper understanding of engineering is another focus. This course is for practitioners.

Course content:
- Getting started
  - Welding a T-Joint with the Welding Wizard; welding solids
  - Welding Wizard online help
  - Key notes
  - Tips and tricks
  - Small but nasty
  - Software architecture
  - Welding a wheel with the Welding Wizard; welding of shells
  - Welding local models with the Welding Wizard
- Modeling welding heat sources
  - Energy per unit length of weld
  - Heat source fitting tool
- Modeling welding clamping tools
- Post-processing
  - Background of computed results
  - Multi-physics post-processing

Suggested next courses: Welding Simulation Engineering – Understanding the Material Background (SWD-2005-WM-A)
Welding Assembly Simulation – Getting it Right (SWD-2005-WA-B)
UNDERSTANDING THE MATERIAL BACKGROUND

Reference:  SWD-2005-WM-A Level: Advanced  Duration: 2 days

Audience:  Engineers from product development, process design and manufacturing dealing with welding processes, from Automotive and Heavy Industry.

Objectives:  First, understand the influence of material properties on the quality of results (how to define the appropriate parameters, what is their sensitivity). Second, learn to create a material database. Finally, understand the background of computed results.

Prerequisites:  Course: Welding Simulation Engineering – Getting it Right (SWD-2005-W-B)

Recommended: basic knowledge of non-linear Finite Element technology and numerical methods, plus a strong understanding of practical welding.

Description:  Creation of a material database, based on the participants’ needs. Discussion on the meaning and consequences of numerical parameters, with the objective of achieving the fastest possible computation without decreased quality of results. Detailed analysis of computed results.

Course content:
- Understanding material details: key points for good results
  - Access to the material database
  - Equation of Leblond
  - Martensite transformation
  - CCT diagrams
    - Leblond – Ferrite / Bainite S 355J 2G 3
    - Martensite S 355J 2G 3
    - Johnson-Mehl-Avrami: 100Cr6
    - Fine tuning with the Jominy test
  - How to model material properties of steel
  - How to get material properties of steel
  - Checklist

Suggested next course:  Welding Simulation Engineering – How to Perform and Document Projects Effectively (SWD-2005-WP-A)

Welding Simulation Engineering – Understanding Numerical Parameters and Nonlinear Geometry (SWD-2005-WN-A)
UNDERSTANDING NUMERICAL PARAMETERS AND NONLINEAR GEOMETRY

Reference: SWD-2005-WN-A Level: Advanced Duration: 1 day

Audience: Advanced designers; simulation engineers; engineers from product development, process design and manufacturing dealing with Welding processes, from Automotive and Heavy Industry.

Objectives: Understand the background of numerical parameter files used in the Welding and Macro Bead Advisor in order to design numerical parameter files for the shortest possible simulation time, whilst keeping good results quality. How to get the best possible simulation models with Finite Elements.

Prerequisites: Course: Welding Simulation Engineering – Getting it Right (SWD-2005-W-B)
Recommended: basic knowledge of non-linear Finite Element technology and of numerical methods.

Description: This course explains the optimized usage of iterative techniques, linear system of equation solvers and automatic time stepping parameters. Discussion of the meaning and consequences of numerical parameters, with the objective of achieving the fastest possible computation without decreased quality of results. Keys to convergence – the optimization of simulation models – are examined.

Course content:
- Understanding iterative techniques
  o Initial Newton
  o Full Newton
  o Modified Newton
  o BFGS
  o Radius of convergence
- Understanding linear system of equation solvers
  o Skyline solver
  o Sparse solver
  o Optimized sparse solver
  o Iterative solver
- Understanding automatic time stepping
- How to choose the best combination of iterative techniques, linear system of equation solvers and automatic time stepping parameters dedicated to individual problems
- How to design numerical parameter files so that users without FEM background must no longer deal with numerical parameters
- What is nonlinear geometry; when to choose a simulation option for nonlinear geometry

Suggested next course: Welding Simulation Engineering – How to Perform and Document Projects Effectively (SWD-2005-WP-A)

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HOW TO PERFORM AND DOCUMENT PROJECTS EFFECTIVELY

Reference: SWD-2005-WP-A
Level: Advanced
Duration: 1 day
Audience: Engineers from product development, process design and manufacturing dealing with welding processes, from Automotive and Heavy Industry.
Objectives: Working under Industrial conditions: Gather data and manufacturing conditions, weigh importance of data, fill out and check quality assurance document prior to simulations, plan pre-work, mesh and run large models, judge results, which results to present, present results in an effective format.
Prerequisites: Course: Welding Simulation Engineering – Getting it Right (SWD-2005-W-B)
Description: Based on an Industrial study, this course explains the most efficient way to work under Industrial conditions.

Course content:
- What to do before starting simulations
  o Gather data and manufacturing conditions
  o Fill out quality assurance document prior to simulations
- How to perform consulting studies with large models in an effective manner
  o Effective understanding of the problem
  o Validate material properties
  o Validate quality of results based on mesh quality
  o Plan the meshing
  o Optimize the numerical performance
  o Set up and run huge models
  o Check numerical performance and result quality
- How to present results in an effective format
  o Which results to present in order to answer the questions of your clients
  o How to present the results

Suggested next course: Training on individual needs

Courtesy: WAGON Automotive GmbH
WELDING ASSEMBLY SIMULATION

Reference: SWD-2005-WA-B
Level: Basic
Duration: 2 days
Audience: Automotive and industry engineers involved in the Welding process

Objectives: Learn to perform Welding Assembly Simulations for large components, which cannot be simulated with transient welding in a reasonable time range.

Prerequisites: Course: Welding Simulation Engineering – Getting it Right (SWD-2005-W-B). Explicitly no knowledge in non-linear Finite Element Analysis is required.

Description: Participants first learn to understand advanced welding assembly simulation methods, and then to set up and run a Welding Assembly simulation. This course is for practitioners.

Course content:
- Generation of standard local models using the local model editor; T, Butt and Overlap
- Generation of individual local models
- Simulation of the Welding Assembly on selected structures
- Getting it right: Checklist

Welding Assembly of a typical chassis component. Courtesy Renault

Please contact your nearest ESI office for further information and to register for this course (see back cover).
WELDING ASSEMBLY SIMULATION OF LARGE HEAVY INDUSTRY STRUCTURES

Reference: SWD-2005-WA-A
Level: Advanced
Duration: 3 days
Audience: Engineers from Heavy Industry
Objectives: Perform welding assembly simulations for large Heavy Industry structures.
Prerequisites: Course: Welding Simulation Engineering – Getting it Right (SWD-2005-W-B) and basic knowledge of Finite Element methods
Description: Participants learn to perform Welding Assembly simulations of large Heavy Industry structures, using Instantaneous Welding, Multi-Pass Welding and the Local-Global method.

Course content:
- Instantaneous welding of Heavy Industry specimen
- Multi-pass-Welding of local models and Heavy Industry specimen
- Welding Assembly using the local-global method and PAM-ASSEMBLY
- Understanding nonlinear geometry
- Welding Assembly using the local-global method, the Assembly Advisor and some advanced simulation technologies

Simulation of a typical stiffener in ship building

Please contact your nearest ESI office for further information and to register for this course (see back cover).
STAMPING AND WELDING SIMULATION COUPLING

Reference: SWD-2005-WS-A
Level: Advanced
Duration: 2 days
Audience: Automotive and Industry engineers involved in Welding manufacturing and planning.
Objectives: Learn to perform Welding Assembly simulations including results from a PAM-STAMP 2G simulation.
Prerequisites: Courses: Welding Simulation Engineering – Getting it Right (SWD-2005-W-B) and Basic PAM-STAMP 2G.
Solid knowledge of Finite Elements methods
Description: Participants learn to couple stamping-welding and welding-stamping simulations. In case of shell-only models, manufacturing simulation results are prepared for post simulation with general purpose FEM programs or crash simulation using PAM-CRASH.
This course is for advanced analysts.

Course content:
- Coupling stamping and welding simulation using the local-global method
- Coupling stamping and welding simulation using the transient welding method, for shell-solid and shell only structures
- Coupling welding and stamping simulation for the purpose of welding stamped tailored blanks
- Getting it right: Checklist

Preparation of the part in PAM-STAMP 2G

Please contact your nearest ESI office for further information and to register for this course (see back cover).
UNDERSTANDING THE THEORETICAL BACKGROUND OF WELDING SIMULATION

Reference: SWD-2005-WT-A
Level: Advanced
Duration: 2 days
Audience: Advanced analysts involved in welding and heat treatment process simulation.
Objectives: Understand the theoretical background of welding simulation.
Prerequisites: Solid knowledge of Finite Elements methods and Welding simulation engineering.
Description: Participants learn about the theoretical background of welding and heat treatment, with focus on heat transfer, phase transformations, changes in the material status and related mechanics.

Course content:
- Understanding heat transfer including phase transformations: basic equations and FEM modeling
- Understanding mechanics including phase transformations: basic equations and FEM modeling
- Understanding material tests to get correct input for welding simulation

Dilatometer test to measure thermal strains

Please contact your nearest ESI office for further information and to register for this course (see back cover).
About ESI Group

ESI Group is a pioneer and world leading provider of digital simulation software for prototyping and manufacturing processes that take into account the physics of materials.

ESI Group has developed an entire suite of coherent, industry-oriented applications to realistically simulate a product’s behavior during testing, to fine tune the manufacturing processes in synergy with the desired product performance, and to evaluate the environment’s impact on product usage.

ESI Group’s product portfolio, which has been industrially validated and combined in multi-trade value chains, represents a unique collaborative, virtual engineering solution, known as the Virtual Try-Out Space (VTOS), enabling a continuous improvement on the virtual prototype. By drastically reducing costs and development lead times, VTOS solutions offer major competitive advantages by progressively eliminating the need for physical prototypes.