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NUMERICAL WELDING SIMULATION — EXECUTION AND DOCUMENTATION

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Presented

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BACKGROUND

Engineering methods have been developed to provide a means of establishing the Fitness-For-Service (FFS) of safety & environmentally critical facilities. Many parts are fabricated by means of welding.

Welds are loaded by the combination of the service generated operational loads and the locked in residual stresses from fabrication.

Computer based methods for the prediction of welding residual stresses have been developed since the 1970s, but recently there has been an acceleration of reliability and interest .

TECHNICAL SPECIFICATION

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Numerical welding simulation — Execution and documentation

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Report of voting

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Answers to Q.1: "Does your National Body approve the attached DTS to go forward to publication?"		
17 x	Approval as presented	China (SAC) Congo, The Democratic Republic of the (OCC) France (AFNOR) Germany (DIN) Greece (NQIS ELOT) India (BIS) Iran, Islamic Republic of (ISIRI) Japan (JISC) Kenya (KEBS) Netherlands (NEN) Portugal (IPQ) Romania (ASRO) Slovakia (SOSMT) Sweden (SIS) Switzerland (SNV) Ukraine (DTR) United Kingdom (BSI)
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies).

The work of preparing International Standards is normally carried out through ISO technical committees.

Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

The committee responsible for this document is ISO/TC 44, *Welding and allied processes*, in collaboration with Technical Committee CEN/TC 121, *Welding and allied processes*.

Numerical welding simulation — Execution and documentation

Scope

This Technical Specification (TS) provides a workflow for the execution, validation, verification, and documentation of a numerical welding simulation within the field of computational welding mechanics (CWM)

This Technical Specification covers the following aspects and results of CWM, excluding simulation of the process itself:

- Heat flow during the analysis of one or more passes;
- Thermal expansion as a result of the heat flow;
- Thermal stresses;
- Development of inelastic strains;
- Effect of temperature on material properties;
- Predictions of residual stress distribution in support of design and assessment of a wide range of components.

- This TS contains a system of weightings that will provide the user with an estimated accuracy level. It is anticipated that these will enable industrial bodies or companies to define required levels of CWM for specific applications;

- It is independent of the software and implementation, and therefore is not restricted to FEA, or to any particular industry.

- **It provides consistent framework for-primary aspects of the commonly adopted methods and goals of CWM (including validation and verification to allow an objective judgment of simulation results).**
- Through presentation and description of the minimal required aspects of a complete numerical welding simulation, an introduction to computational welding mechanics (CWM) is also provided.
- Examples are provided to illustrate the application of this Technical Specification, which can further aid those interested in developing CWM competency.

Description of the problem

- Computational welding mechanics is a subset of numerical simulation and analysis of welding that is primarily accomplished through use of the finite element method.
- Nonlinear thermal and mechanical analyses are performed, which can be sequentially or fully coupled, where the welding power is applied to the computational model in a specified way, and the resulting transient temperature (and possibly microstructure) fields are then combined with mechanical material properties/models and boundary conditions to predict the stress and strain in the model and its distortion.
- This TS addresses the general CWM problem, which can be defined as a three dimensional solid element model employing a travelling power density heat source with simultaneous calculation of temperature, microstructure and displacement, utilizing elasto-visco-plastic constitutive models based on material properties ranging from room temperature to beyond the melting temperature.

Physical model

Depending on the desired model complexity, the following exemplary physical effects and influencing variables can be relevant:

- Heat transport via heat conduction in the solid;
- Convection and radiation at the surface;
- Stress versus strain;
- Materials changes such as microstructure transformations;
- Dissolution or precipitation;
- Mechanical behaviour such as elasticity;
- Instantaneous or time dependent-plasticity;
- Strain hardening and recovery effect;
- Thermal expansion;
- Transformation induced plasticity.

Mathematical model and solution method

- Based on the physical model, a correspondingly suited mathematical model shall be defined.
- To do this, the underlying essential differential equations shall be given or referred to. This definition concern the geometrical model (2D, 3D), supplemented by the mathematical description of the heat source as well as of the initial and boundary conditions.

- In case of general purpose commercial mechanical analysis software, the selected options of the mathematical solution should be summarized.
- Although the typical envisaged solution method is finite element method (FEM), the solution method should always be stated, e.g. analytical method, different or complementary numerical method, or stochastic approach.

Workflow

- **The numerical modeling [choice of finite elements (FE), discretization, solver, etc.] is a part of computational solid mechanics specialist's job and not in the scope of this Technical Specification.**
- The reader is referred to ASME V&V which provides a detailed framework for verification and validation (or "validation and verification") of general computational solid mechanics and also to R6 for a standardized technique for CWM.

Material properties

- Accuracy of the prediction by CWM relies in part on the accuracy of thermo-physical and thermo-mechanical properties used by the models.
- Material properties uncertainty can be greatly reduced by state of the art testing; however, even in this case, property determination is not possible over the full temperature range of the welding problem.
- Therefore, assumptions are inherent to selection of material properties, and shall be thoroughly documented.

Model scale and scope

One of the primary choices to be made for a CWM model is the model scale and scope. If the exact description is not implemented in the simulation model, then an assumption or simplification has been applied to the problem.

3D modeling and analysis is the most rigorous approach for CWM; this is because the welding process is inherently 3D and intensely local for all but the fastest welding speeds or thinnest sections.

2D models are also useful for heavy section multi-pass welds to qualitatively investigate the impact of weld sequence changes and major geometric changes.

Analysis coupling

CWM often uses a sequentially-coupled approach, where the mechanical analysis follows the thermal analysis.

The sequentially-coupled approach is usually valid because the couplings of thermal, metallurgical, and mechanical effects are mostly one-way in fusion welding.

For instance, the mechanical stress and deformation, such as temperature rise by plastic work is not expected to have much influence on the temperature distribution; nor do they affect most phase transformations.

The sequentially-coupled approach is much less demanding computationally than the fully-coupled approach.

Validation and verification

For quality assurance of the simulation results, the following essential measures are at the user's disposal depending on the application case and on the defined simulation goals.

- **Verification of the simulation model**

For verifying the simulation model, the following options are available:

— Tests of consistency between the physical model (4.4), the mathematical model and the solution method;

— Confirmation by using different solution methods (numerical and analytical) and comparison with simplified cases (e.g. reduction in dimensionality, rough calculation);

— Quantification of the influence of discretization variation (spatial and temporal) on the calculation result;

— Proof of the range of validity by parameter study.

- **Calibration of the model parameters**

Calibration comprises the determination of the variable model parameters (e.g. process parameters, clamping conditions, material characteristics) from the comparison with experimental data, or alternatively with computational results which have not been used for the verification or validation.

Calibration of the thermal model can be accomplished, for example, by using simplified test pieces or smaller parts of local cuts of the simulation object. This implies that the calibration is not generally valid, but relates to a concrete application case.

As the stress-strain behaviour is critical, it could be estimated more accurately by comparison of residual stress computational results with reliable experimental data.

- **Validation of the simulation results**

A validation of the simulation results shall be done according to at least one of the following criteria:

— Complete or partial comparison between calculation results and data gained from validation experiments, e.g. temperature; weld pool geometry, distortion, residual stresses;

— Demonstration that the system performance of the simulation model is in agreement with real conditions, e.g. by sensitivity analysis or parameter study

- **Validation experiment guidelines**

1. An experiment that is to be used to validate a weld model for particular phenomena of interest should be very carefully designed; see for example ASME V&V for a detailed explanation of general verification and validation principles.
2. Care shall be taken to ensure the reproducibility of the experiment. The experiment is best designed by first simulating the experiment with the weld model.
3. The validation is not necessarily to be performed on the full simulation object.
4. The design of a good mock-up requires a trade-off study of cost and time in building the mock-up versus similarity of the mock-up to the real structure.

Reporting/display of results

For traceability, the overall approach shall be documented in the form of a report.

Any non-consideration of the optional measures according to this TS shall be justified briefly.

Simulation object

Description of the major scope of the project, of the sequential steps, of the simulation, and the principal assumptions;

Expectations of the study (result quality, most important results needed).

- **Material properties and input data**

- Description of all the materials, including their models and chemical composition, that are used in the welding process (literature, own data including measurement method), uncertainties, and units of material data;

- Temperature dependent data should be displayed for both thermo-physical (thermal conductivity, density, specific heat, enthalpy, thermal expansion coefficient) and thermo-mechanical properties (Young’s modulus, Poisson’s ratio, strain hardening model parameters, yield stress, plasticity model parameters) .

- **Process parameters**

— Parameters of the welding process e.g. welding current, welding voltage, welding efficiency, welding speed, welding position;

— Description and parameters of the simulation heat source.

- **Meshing**

— Few images of the part to be simulated and a few significant images of the computational mesh regarding the simulation objectives;

— Number of node and elements, mesh size and type/shape functions of the elements.

- **Numerical model parameters**

— type of transient computation;

— solution method (e.g. static FEA);

— algorithm to reach physical equilibrium (e.g. implicit, iterative);

— values of absolute or relative precisions to reach physical equilibrium;

— values of typical time stepping (time incrementation criteria);

— initial and boundary conditions.

- **Analysis of results**

Care shall be taken in the evaluation and result display to bring the presentation layout into line with the definition of the simulation objective.

