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Numerical welding simulation — Execution and documentation

Simulation numérique de soudage — Exécution et documentation

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 44, *Welding and allied processes*.

Requests for official interpretations of any aspect of this Technical Specification should be directed to the Secretariat of ISO/TC 44 via your national standards body. A complete listing of these bodies can be found at www.iso.org.

Numerical welding simulation — Execution and documentation

1 Scope

This Technical Specification provides a workflow for the execution, validation, verification and documentation of a numerical welding simulation within the field of computational welding mechanics (CWM). As such, it primarily addresses thermal and mechanical finite element analysis (FEA) of the fusion welding (see ISO/TR 25901:2007, 2.165) of metal parts and fabrications.

CWM is a broad and growing area of engineering analysis.

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 distributions;

— predictions of welding distortion.

This Technical Specification refers to the following physical effects, but these are not covered in depth:

— physics of the heat source (e.g. laser or welding arc);

— physics of the melt pool (and key hole for power beam welds);

— creation and retention of non-equilibrium solid phases;

— solution and precipitation of second phase particles;

— effect of microstructure on material properties.

The guidance given by this Technical Specification has not been prepared for use in a specific industry. CWM can be beneficial in design and assessment of a wide range of components. It is anticipated that it will enable industrial bodies or companies to define required levels of CWM for specific applications.

This Technical Specification is independent of the software and implementation, and therefore is not restricted to FEA, or to any particular industry.

It provides a 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).

Clause 4 of this Technical Specification provides more detailed information relating to the generally valid simulation structure and to the corresponding application. Clause 5 refers to corresponding parts of this Technical Specification in which the structure for the respective application cases is put in concrete terms and examples are given. Annex A presents a documentation template to promote the consistency of the reported simulation results.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 25901, *Welding and related processes — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 25901 and the following apply.

3.1
boundary conditions
conditions imposed at the spatial boundary of a computational model that describe the interaction between the modelled and unmodelled domains

Note 1 to entry: Complete boundary conditions provide a unique solution to the specific mathematical problem being solved.

3.2
geometric model
description of all geometries analysed within a simulation including the dimensionality of the simulation object

3.3
mathematical model
model comprising the underlying essential mathematical equations including the appropriate initial and boundary conditions

3.4
numerical simulation
simulation performed by adopting approximate mathematical methods generally performed on a computer

3.5
physical model
full array of the physical process to be simulated and boundary and initial conditions relevant to the simulation object as well as adopted simplifications and assumptions

3.6
plausibility check
check of the obtained calculation results in respect of their conformity with basic physical principles

3.7
simulation model
combination of the physical, geometrical and mathematical models and the solution method

3.8
spatial discretization
distribution and type of the geometric units for subdividing the geometric model

3.9
temporal discretization
step size and number of time units for subdividing the duration being modeled

3.10
validation
process of determining the degree to which a model is an accurate representation of the physical problem from the perspective of the intended uses of the model

3.11
validation experiment
experiment designed specifically for validating the simulation results taking account of all relevant data and their uncertainty

3.12
verification
demonstration of the correctness of the simulation model

3.13
calibration
process of adjusting modelling parameter values in the simulation model for the purpose of improving agreement with reliable experimental data

3.14
model
mathematical representation of a physical system or process

3.15
finite element analysis
FEA
numerical method for solving partial differential equations that describes the response of a system to loading

3.16
heat flux
rate at which thermal energy is transferred through a unit area of surface

3.17
power density
amount of thermal power absorbed or generated per unit volume

3.18
prediction
estimation of the response of a physical system using a mathematical model

3.19
computational welding mechanics
CWM
subset of numerical simulation and analysis of welding

4 Description of the problem

4.1 General

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 some 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 description is not intended to be all inclusive or restrictive, but is provided to establish the typical expected use to which this Technical Specification might apply.

This Technical Specification 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.

This does not preclude use of simplified methods, but rather provides a simulation method benchmark from which simplifications can be judged. The need for simplifications are primarily driven by computational limitations (size and speed), and apply to many industry problems, such as heavy section welds in the pressure vessel or shipbuilding industries. As any simplification of the mathematical model that represents the physical system may increase uncertainty in the simulation results, this shall be counterbalanced with more effort in verification and validation of the model. Note that all computational models require verification and validation, and this subject is addressed in greater detail in Clause 6. The preceding discussion is formalized and expanded upon in the remaining subclauses.

4.2 Simulation object

The first item comprises the exact description of the component or overall structure, respectively, to be investigated (e.g. geometry, service conditions), of the employed base and filler materials, of the welding procedure and parameters, of the applied welding sequence as well as of the restraint conditions. Optionally, a complementary graphical representation or photograph may be attached.

4.3 Simulation objectives

This item concerns the definition of the desired simulation results which ensue from the real task at hand. This is particularly important since many realistic problems still require simplification in order to be analysed with reasonable effort.

Examples include the calculation of welding residual stresses and/or distortions, the assessment of the heat affected zone and its characteristics or the welding procedure net heat input.

In addition, the ultimate aim should be stated to which the desired simulation results are intended to be further applied, such as:

— assessment of the structural integrity of the object under specified service loading conditions, possibly including postulated or known material faults;

— optimization of necessary post weld treatment processes for the relief of welding distortions and/or residual stresses;

— optimization of welding procedures;

— minimization of welding distortion and stresses.

4.4 Physical model

Depending on the objectives defined in 4.3, this item concerns the compilation of the respective appropriate physical effects, boundary conditions and adopted simplifications and assumptions to be simulated. 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 dependant-plasticity;

— strain hardening and recovery effect;

— thermal expansion;

— transformation induced plasticity.

These factors can be described either by text, graphs, tables, or formulae. The real boundary conditions, most especially initial temperature in the solid, room temperature, and clamping conditions shall be described purposefully.

The simplifications that have turned out to be necessary when defining the simulations goals and that will be adopted in performing the simulation shall be described. The subsequent assumptions shall be justified by verification and validation procedures detailed in Clause 6.

4.5 Mathematical model and solution method

Based on the factors compiled in 4.4, a correspondingly suited mathematical model shall here 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 stochastical approach.

4.6 Implementation

The description of the implementation comprises specific details relating to the simulation object according to 4.2 and concerning the spatial discretization, e.g.:

— FE-meshing including the specification of the element types;

— temporal discretization;

— material characteristics;

— initial and boundary conditions.

The result of the implementation is the simulation model.

5 Workflow

5.1 General

The numerical modelling [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 [2] which provides a detailed framework for verification and validation (or "validation and verification") of general computational solid mechanics and also to R6 [3] and AWS A9.5 [4] for a standardized technique for CWM.

Following description of the workflow, recommended methodology for verification and validation (or "validation and verification") is given in the next clause.