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EASI-STRESS

EUROPEAN ACTIVITY FOR STANDARDISATION OF INDUSTRIAL RESIDUAL STRESS CHARACTERISATION

H2020 NMBP-35-2020

Grant Agreement Number: 953219

EASI-STRESS

Deliverable Report:

D5.1 Output data report

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EASI-STRESS

Project Deliverable Information Sheet

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Document Control Sheet

Document	Title: Output data report	
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Authorship	Written by	Vincent Robin, EDF
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	Approved	Nikolaj Zangenberg, DTI

List of Abbreviations

BCC	Body-Centered Cubic
CAD	Computer Aided Design
DHD	Deep-hole drilling
EDF	Energie de France (project partner)
FCC	Face-Centered Cubic
FE	Finite Element
GTAW	Gas Tungsten-Arc Welding
HAZ	Heat affected zone
iDHD	Incremental deep-hole drilling
ISO	International Organization for Standardization
NeT	European Network on Neutron Techniques Standardization for Structural Integrity
PLM	Product Life Management
SAW	Submerged-Arc Welding
SMAW	Shielded Metal-Arc Welding
TC	Technical Committee
TIG	Tungsten Inert Gas
TS	Technical Standard
WRS	Weld Residual Stress

IP	Intellectual Property
IPR	Intellectual Property Rights
CA	Consortium Agreement
GA	Grant Agreement
PC	Project Coordinator
EB	Executive Board
IMT	Innovation Management Team
RTO	Research and Technology Organisations
LRI	Large-scale Research Infrastrutures
CEN	European Committee for Standardization
TS	Technical Specification

Table of Contents

1. Introduction

In conjunction with WP4 which informs residual stress calculation from experimental data (data processing and experimental parameters input for FE-modelling), it is necessary to provide an appropriate format of data exploitable for direct comparison to modelled outputs. This will necessitate identifying a route which is the most compatible with non-commercial (open source) and commercial FE software, including both metrology of components and their data features as well as the resolved stress at discrete locations. This task will provide a raw and meta data file format suitable to developed a reliable approach to compare stresses determined by various techniques. The file format is a simple ascii format based on universal format (http://sdrl.uc.edu/sdrl/referenceinfo/universalfileformats) and compatible with .hdf5 philosophy available in Python (https://vitables.org/) and intensively used in scientific computing.

A simple format is proposed in the document for sharing residual stress results (1D profiles or 2D/3D maps). Based on ISO standards for welding simulation [1], a subsequent template is presented to detail the object of the simulation from where output data are exported. This template is similar to the one developed within EASI-STRESS WP4 for the description of instrumental set-up, and can be extended to other manufacturing process simulation (casting, forging, machining…). The document could be reviewed during the duration of the project thanks to the evolution of European standardization in the domain of activity:

- European Network on Neutron Techniques Standardization for Structural Integrity (NeT) [2]. This network develop experimental and numerical techniques and standards for the reliable characterization of residual stresses in structural welds. A focus on Task Group 6 activity is made in the current document as TG6 mock-up [3]is the transposition use case for pressure vessel and piping equipment (object of the simulation and experiments within EASI-STRESS for industrial validation),
- ISO/TC 44 decides in October 2021 to revise ISO/TS 18166:2016 “Numerical welding simulation – Execution and documentation”: Development track: 36 months.

2. Example of simulation workflow

Note: The used template for welding simulation can be extended to other manufacturing processes.

As proposed by the project partner EDF, the use of NeT TG6 specimen as a support to validation of development performed within the framework of EASI-STRESS project gives reliability for industrial purpose: transposition mock-up relative to industrial needs, validation of Weld Residual Stress determination techniques.... Indeed, this specimen has the advantage to be well characterised for measurements and simulation of Weld Residual Stress (WRS) as it has been intensively used as a support to research and development activity within NeT project: European network to develop accurate experimental and numerical methods to assess residual stresses in structural weldments. The NeT Task Group 6 or TG6 project examined an Alloy 600 plate containing a three-pass slot weld made with Alloy 82 consumables. A number of identical specimens were fabricated and detailed records of the manufacturing history were achieved. Parallel WRS measurement and simulation round robins were performed. WRS were measured using neutron diffraction at five different instruments. The acquired database is large enough to generate reliable mean profiles, to identify clear outliers, and to establish the systematic uncertainty associated with this non-destructive technique. TG6 gives a valuable insight into the real-world variability of diffraction-based WRS measurements, and forms a reliable foundation against which to benchmark other measurement methods. The mean profile of measured WRS was used to validate the accuracy achieved by the network on the prediction of WRS thanks to Finite Element (FE) simulation (see TG6 mock-up BD line stress profile in the middle of the plate §Proposed file format for sharing Residual Stress distribution).

2.1 Simulation object and objectives

For traceability, the overall approach shall be documented in the form of a report in accordance with the simulation object, objective and subsequent simulation workflow. Such a documentation template should at least contain the given items:

- 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
- Process parameter
- Meshing
- Numerical model parameters
- Analysis of results
  - For instance: graphical and tabular representations with brief text descriptions, also with a view to assuring the simulation results according to the validation and verification.

The following forms can be used for traceability and V&V (Validation & Verification) of the simulation results, giving confidence and auditability to simulation results (i.e. WRS). The user of this form is allowed to copy this present form prejudice to the property rights of ISO to the entirety of the Technical Specification ISO/TS 18166:2016.

Company name: EDF Division: R&D	Documentation of welding simulation according to ISO/TS 18166:2016	Project: EASI-STRESS Variant/Version: 1.0 Date: 2021-05-25 Page 1 of 1

Cover sheet for brief descriptions

Simulation object: (optionally, a complementary graphical representation or photograph may be attached)

Thermo-metallurgical and mechanical simulation of multi-pass TIG welding of a homogeneous configuration: deposition of FM82 (Nickel-based alloy) on Alloy 600 (Nickel-based alloy).

Simulation objectives:

Determine the residual stresses in the assembly. These estimates are compared in the end-of-production state with other estimates by calculation and measurement achieved in the framework of the NeT network activities (https://www.net-network.eu).

Physical and mathematical model:

Thermal and mechanical non-linear transient computation, implicit resolution.

Solution method and applied software products:

Weak thermo-mechanical coupling at each pass, two-dimensional modelling in generalised plane strains (plate/sheet) or three-dimensional modelling.

Summary of the results and conclusions:

Results ongoing and completed within EASI-STRESS project:

- Method for comparison (metrics, applied mathematics tools, …)
- Explanation on differences with measurements and between different measurements / different simulations
- Uncertainty quantification

Summary of the measures taken to ensure the quality of the simulation results:

Input data book for welding simulation + Follow-up of the recommendations of the ISO/TS18166 simulation workflow.

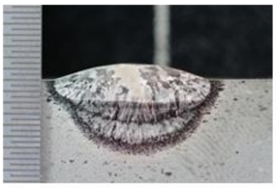
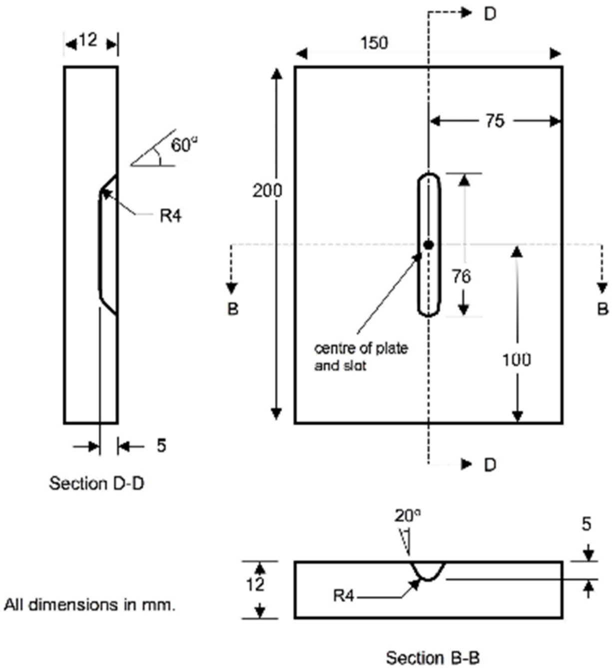
Assurance of the simulation results	Remarks / Explanatory statements
Verified [X] Yes [ ] No	
Calibrated [X] Yes [ ] No	Comparison with thermal cycling during welding, hardness measurements across joints and tensile tests at various points in the weld (base metal, HAZ and deposit metal).
Plausibility [X Yes [ ] No	
Validated [X] Yes [ ] No	Comparison with residual stress profiles measured by iDHD and DHD and diffraction methods.

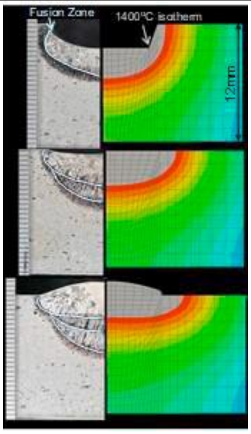
Miscellaneous

Notes (optional):

2.2 Simulation workflow description

Computer based methods for the prediction of welding residual stresses have been developed since the 1970s, but there has been an acceleration of reliability and interest more recently [4]. A global overview of good practice based on the experiences of engineers from many countries so that residual stress prediction becomes a reliable engineering activity for the review of the safety of welded fabrications has been achieved thanks to an ISO/TC 44/Working Group. The Working Group (ISO/TC 44/WG5 Welding Simulation) has prepared the Technical Specification ISO/TS 18166 [1]. The final document is relatively limited when compared to the considerable range of methods, materials and welding processes that could have been explicitly covered [5]. Then we propose to use the form bellow to explicitly describe the model use to produce Finite Element Simulation of Weld Residual Stresses. This document is a part of the protocol, which describe the fabrication of TG6 mock-up among NeT TG6 participants. It gives key parameters for manufacturing simulation specialists and specialist in charge of experimental WRS determination.

Geometry	
Actual and/or schematic view	PLATE with a central slot   
Mesh	Mesh example

	 
Diameter if tube [mm]	
Length [mm]	200
Width if plate [mm]	150
Thickness [mm]	12
Machining	-
Configuration	
Tube / Plate	Plate
Welding process (SMAW, SAW, GTAW,…), Manual / auto	GTAW auto
Welding position (moving part / moving torch) and clamping	In horizontal postion (flat), no clamp
Modelling	
Dimension	2D / 3D
Hpothesis	Generalized plane strains if 2D
Physics	Thermal -Mechanical
Material	
Base Metal MB1	Alloy 600
Base Metal MB2	Alloy 600
Buttering B1	-
Buttering B2	-
Filler Metal MA1	Alloy FM82
Welding process	
Parameters01 (mean values)	GTAW - U 11 [V] I 220 [A] V_S 1.17 [mm/s] V_f 28,33 [mm/s] Diam 1.0 [mm] R 0.7
Parameters01 (min values)	-
Parameters01 (max values)	-

Parameters02 (mean values)	GTAW - U 13 [V] I 220 [A] V_S 1.17 [mm/s] V_f 28,33 [mm/s] Diam 1.0 [mm] R 0.7
Parameters02 (min values)	-
Parameters02 (max values)	-
Parameters03 (mean values)	GTAW - U 12 [V] I 220 [A] V_S 1.17 [mm/s] V_f 28,33 [mm/s] Diam 1.0 [mm] R 0.7
Parameters03 (min values)	-
Parameters03 (max values)	-
Specific prescriptions	
Preheating [°C]	-
Postheating [°C]	-
Interpass [°C]	50°C
Welding sequence	
Pass position	
Tack weld PASSE001 PASSE002 PASSE003	No (one-piece plate) Parameters01 Parameters02 Parameters03
PWHT (Post-Weld Heat Treatment)	
Heating and cooling velocity [°C/h]	-
Holding temperature [°C]	-
Holding time [h]	-

3. Proposed file format for sharing Residual Stress distribution

3.1 METADATA – simulation

The main metadata that can be used to analyse WRS output based on measurement and simulation are described in this paragraph. In conjunction with data on residual stress distribution (profile and/or 2D, 3D maps described in the next paragraph), it allows to make relevant post-processing:

- comparison in space,
- average inside a gauge volume,
- data processing
  - mean,
  - standard deviation,
  - Uncertainties Quantification (UQ)…

The proposed format is an ascii file following these rules for syntax and content as shown in the text box below.

Base Metal (BM) chemical composition 1 – **BM 1**

Fe	**C**	**Mn**	**Si**	**Ni**	**Cr**	**Mo**	**Cu**	**S**	**P**	**Al**	**<V**	**Nb Ti**

BM1 Crystallographic structure: FCC / BCC

…

BM1 elastic properties (macroscopic) at room temperature 20°C: E [MPa], Nu

…, …

Base Metal (BM) chemical composition 2 – **BM2**

…

BM2 Crystallographic structure: FCC / BCC

…

BM2 elastic properties (macroscopic) at room temperature 20°C: E[MPa], Nu

…

Filler Metal (FM) chemical composition 1 – **FM1**

FM1 Crystallographic structure: FCC / BCC

FM1 elastic properties (macroscopic) at room temperature 20°C: E[MPa], Nu

3.2 DATA – Residual stress and strain distribution + Gauge volume

The file must contain the position in cartesian coordinates (includes the component reference position and axis direction) of the residual stress values with the stress tensor at that point, elastic strain tensor, material reference to METADATA, gauge dimension, and volume.

The system of coordinate is defined by the simulation model (Finite Element mesh performed from the PLM CAD). It is up to the person in charge of the measurements to put their data back into the CAD/FE model coordinate system.

The file format should, thus, include the following parameters:

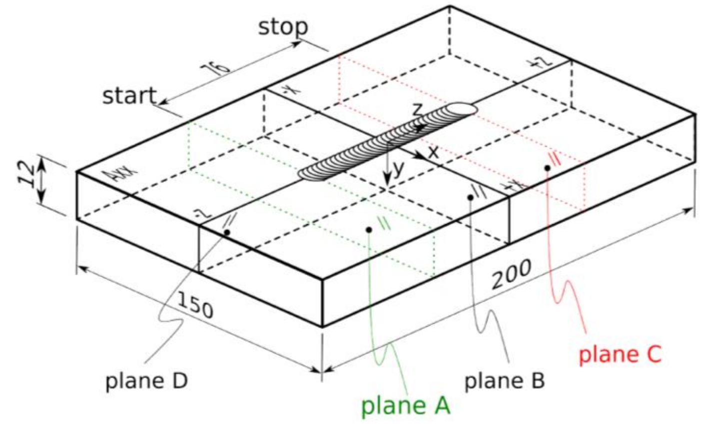
X, Y, Z [mm], Sxx, Syy Szz [MPa], Sxy, Sxz, Syz [MPa],Eexx, Eeyy,… Material (BM1, FM1…), DX, DY, DZ (approx. volume box), Volume

In cases of non-cubic gauge volumes, the parameters should also include descriptions of the gauge volume.

3.3 Example (BD Line TG6).

This paragraph gives an example of simulation results performed on TG6 specimen.

Coordinate system and reference point **Error! Reference source not found.**



METADATA file:

Base Metal (BM) chemical composition 1 – **BM 1**														
	Fe	**C**	**Mn**	**Si**	**Ni**	**Cr**	**Mo**	**Ti**	**Cu**	**S**	**P**	**Al**	**<V**	**Nb**
	9,33	**0.07**	**0.48**	**0.12**	**74.35**	**15.54**	**-**	**0.006**	**-**	**0.001**	**-**	**-**	**-**	**0.1**
BM1 Crystallographic structure : FCC / CC														
FCC														
BM1 at elastic properties (macroscopic) at room temperature 20°C : E [MPa], Nu														
E	**213700**													
Nu	**0,31**													
Base Metal (BM) chemical composition 2 – **BM2**														
None														
BM2 Crystallographic structure: FCC / CC														
None														
BM2 elastic properties (macroscopic) at room temperature 20°C : E[MPa], Nu														
None														
None														
Filler Metal (FM) chemical composition 1 – **FM1**														
	Fe	**C**	**Mn**	**Si**	**Ni**	**Cr**	**Mo**	**Ti**	**Cu**	**S**	**P**	**Al**	**<V**	**Nb**
	0.59	**0.009**	**3.25**	**0.08**	**72.7**	**20.8**	**-**	**0.319**	**-**	**0.001**	**-**	**-**	**-**	**0.1**
FM1 Crystallographic structure: FCC / CC														
FCC														
FM1 elastic properties (macroscopic) at room temperature 20°C : E[MPa], Nu														
E	**213700**													
Nu	**0,31**													

WRS distribution DATA file:

reference (used to shift X in the right coordinate system)	X	Y	Z	Sxx	Syy	Szz	Sxy,Sxz,Syz, Eexx, Eeyy,...	FMterial	DX	DY	DZ	Volume
0	0	1,4277	0	0	-44,7484	274,412	...	FM1	0,25	0,25	0,25	0,015625
0,268555	0	1,159145	0	0,103194	-44,7484	274,412	...	FM1	0,25	0,25	0,25	0,015625
0,537109	0	0,890591	0	1,715	-40,1249	277,861	...	FM1	0,25	0,25	0,25	0,015625
0,805664	0	0,622036	0	2,72913	-35,9138	280,786	...	FM1	0,25	0,25	0,25	0,015625
1,07422	0	0,35348	0	2,43865	-34,2428	281,653	...	FM1	0,25	0,25	0,25	0,015625
1,61133	0	-0,18363	0	4,61889	-26,1195	288,769	...	FM1	0,25	0,25	0,25	0,015625
1,87988	0	-0,45218	0	4,85722	-22,5368	290,825	...	FM1	0,25	0,25	0,25	0,015625
2,14844	0	-0,72074	0	5,11344	-20,2001	292,161	...	FM1	0,25	0,25	0,25	0,015625
2,41699	0	-0,98929	0	6,20552	-13,3711	299,891	...	FM1	0,25	0,25	0,25	0,015625
2,68555	0	-1,25785	0	6,11882	-10,0566	298,269	...	FM1	0,25	0,25	0,25	0,015625
2,9541	0	-1,5264	0	7,02525	-6,85453	300,253	...	FM1	0,25	0,25	0,25	0,015625
3,22266	0	-1,79496	0	7,43014	-3,33813	305,827	...	FM1	0,25	0,25	0,25	0,015625
3,49121	0	-2,06351	0	6,7578	-1,7671	302,97	...	FM1	0,25	0,25	0,25	0,015625
3,75977	0	-2,33207	0	7,44439	1,8671	305,007	...	FM1	0,25	0,25	0,25	0,015625
4,02832	0	-2,60062	0	7,77833	4,61314	306,465	...	FM1	0,25	0,25	0,25	0,015625
4,29688	0	-2,86918	0	7,03182	7,57301	307,701	...	FM1	0,25	0,25	0,25	0,015625
4,56543	0	-3,13773	0	8,34296	11,8966	314,604	...	FM1	0,25	0,25	0,25	0,015625
4,83398	0	-3,40628	0	8,02978	14,4454	315,233	...	FM1	0,25	0,25	0,25	0,015625
5,10254	0	-3,67484	0	8,02978	14,4454	315,233	...	FM1	0,25	0,25	0,25	0,015625
5,37109	0	-3,94339	0	7,62082	16,1711	316,097	...	FM1	0,25	0,25	0,25	0,015625
5,63965	0	-4,21195	0	8,04007	19,18	317,633	...	FM1	0,25	0,25	0,25	0,015625
5,9082	0	-4,4805	0	8,02689	20,7702	318,155	...	FM1	0,25	0,25	0,25	0,015625
6,17676	0	-4,74906	0	8,20106	21,8717	317,823	...	FM1	0,25	0,25	0,25	0,015625
6,44531	0	-5,01761	0	8,0743	23,0791	389,334	...	BM1	0,25	0,25	0,25	0,015625
6,71387	0	-5,28617	0	8,0743	23,0791	389,334	...	BM1	0,25	0,25	0,25	0,015625
6,98242	0	-5,55472	0	8,02291	20,8731	385,535	...	BM1	0,25	0,25	0,25	0,015625
7,25098	0	-5,82328	0	8,02904	19,484	382,66	...	BM1	0,25	0,25	0,25	0,015625
7,51953	0	-6,09183	0	8,02904	19,484	382,66	...	BM1	0,25	0,25	0,25	0,015625
7,78809	0	-6,36039	0	7,51242	17,306	380,402	...	BM1	0,25	0,25	0,25	0,015625
8,05664	0	-6,62894	0	7,265	15,8796	378,664	...	BM1	0,25	0,25	0,25	0,015625
8,3252	0	-6,8975	0	7,265	15,8796	378,664	...	BM1	0,25	0,25	0,25	0,015625
8,59375	0	-7,16605	0	6,82445	13,5466	374,511	...	BM1	0,25	0,25	0,25	0,015625
8,8623	0	-7,4346	0	5,97712	11,4105	370,915	...	BM1	0,25	0,25	0,25	0,015625
9,13086	0	-7,70316	0	5,97712	11,4105	370,915	...	BM1	0,25	0,25	0,25	0,015625
9,39941	0	-7,97171	0	5,4292	9,40479	367,621	...	BM1	0,25	0,25	0,25	0,015625
9,66797	0	-8,24027	0	4,778	7,09773	365,001	...	BM1	0,25	0,25	0,25	0,015625
9,93652	0	-8,50882	0	3,84643	5,10039	362,385	...	BM1	0,25	0,25	0,25	0,015625
10,2051	0	-8,7774	0	3,84643	5,10039	362,385	...	BM1	0,25	0,25	0,25	0,015625
10,4736	0	-9,0459	0	3,56634	3,69687	360,786	...	BM1	0,25	0,25	0,25	0,015625
10,7422	0	-9,3145	0	2,44075	1,44656	351,49	...	BM1	0,25	0,25	0,25	0,015625
11,0107	0	-9,583	0	2,44075	1,44656	351,49	...	BM1	0,25	0,25	0,25	0,015625
11,2793	0	-9,8516	0	2,19124	0,130373	350,168	...	BM1	0,25	0,25	0,25	0,015625
11,5479	0	-10,1202	0	1,46094	-1,92872	355,388	...	BM1	0,25	0,25	0,25	0,015625
11,8164	0	-10,3887	0	1,46094	-1,92872	355,388	...	BM1	0,25	0,25	0,25	0,015625
12,085	0	-10,6573	0	0,895745	-3,81604	353,527	...	BM1	0,25	0,25	0,25	0,015625
12,3535	0	-10,9258	0	0,509079	-5,59128	352,421	...	BM1	0,25	0,25	0,25	0,015625
12,6221	0	-11,1944	0	0,509079	-5,59128	352,421	...	BM1	0,25	0,25	0,25	0,015625
12,8906	0	-11,4629	0	0,210667	-6,93137	351,141	...	BM1	0,25	0,25	0,25	0,015625
13,1592	0	-11,7315	0	0,0232434	-8,71861	350,405	...	BM1	0,25	0,25	0,25	0,015625
13,4277	0	-12	0	0,0232434	-8,71861	350,405	...	BM1	0,25	0,25	0,25	0,015625

3.4 Python script data treatment (HDF5 format)

A HDF5 wrapper can be used to convert “csv” file into “binary HDF5” files.

https://pandas.pydata.org/pandas-docs/stable/user_guide/io.html#read-write-api

An example of Python script will be proposed after convergence on the file format in connection with WP4 activities.

4. Conclusions

All the data (experimental data and simulation data) will be presented with the same system of coordinate as position in cartesian coordinates, residual stress tensors, Elastic Strain Tensor, Material reference to METADATA, Gauge dimension, Volume.

X, Y, Z [mm], Sxx, Syy Szz [MPa], Sxy, Sxz, Syz [MPa],Eexx, Eeyy,... Material (BM1, FM1...), DX, DY, DZ (approx. volume box), Volume

To describe the simulation work on the component, the partners could use the following template.

<table>
<tr><td>Company name: XX

Division: XX</td><td colspan="2">Documentation of XXX simulation</td><td>Project: EASI-STRESS
Variant/Version: 1.0
Date: 2021-05-25
Page 1 of 1</td></tr>
<tr><td colspan="4">Cover sheet for brief descriptions</td></tr>
<tr><td colspan="4">Simulation object: (optionally, a complementary graphical representation or photograph may be attached)</td></tr>
<tr><td colspan="4">Simulation objectives:</td></tr>
<tr><td colspan="4">Physical and mathematical model:</td></tr>
<tr><td colspan="4">Solution method and applied software products:</td></tr>
<tr><td colspan="4">Summary of the results and conclusions:
-</td></tr>
<tr><td colspan="4">Summary of the measures taken to ensure the quality of the simulation results:</td></tr>
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<tr><td colspan="2">Verified [X] Yes [ ] No</td><td colspan="2"></td></tr>
<tr><td colspan="2">Calibrated [X] Yes [ ] No</td><td colspan="2"></td></tr>
<tr><td colspan="2">Plausibility [X Yes [ ] No</td><td colspan="2"></td></tr>
<tr><td colspan="2">Validated [X] Yes [ ] No</td><td colspan="2"></td></tr>
<tr><td colspan="4">Miscellaneous</td></tr>
<tr><td colspan="4">Notes (optional):</td></tr>
<tr><td colspan="4">Geometry</td></tr>
<tr><td colspan="2">Actual and/or schematic view</td><td colspan="2"></td></tr>
<tr><td colspan="2">Mesh</td><td colspan="2">Mesh example</td></tr>
<tr><td colspan="2">Diameter if tube [mm]</td><td colspan="2"></td></tr>
<tr><td colspan="2">Length [mm]</td><td colspan="2"></td></tr>
<tr><td colspan="2">Width if plate [mm]</td><td colspan="2"></td></tr>
<tr><td colspan="2">Thickness [mm]</td><td colspan="2"></td></tr>
<tr><td colspan="2">Machining</td><td colspan="2">-</td></tr>
<tr><td colspan="4">Configuration</td></tr>
</table>

Tube / Plate	
Process specification	
Modelling	
Dimension	2D / 3D
Hpothesis	
Physics	
Material	
Base Metal MB1	
Base Metal MB2	
Buttering B1	-
Buttering B2	-
Filler Metal MA1	
Process	
Parameters01 (mean values)	
Parameters01 (min values)	-
Parameters01 (max values)	-
Specific prescriptions	
Preheating [°C]	-
Postheating [°C]	-
Interpass [°C]	50°C
Process sequence	
Pass position	
Post-treatment)	
Heating and cooling velocity [°C/h]	-
Holding temperature [°C]	-
Holding time [h]	-

References

[1] CEN ISO/TS 18166:2016, ***Numerical welding simulation — Execution and documentation***, 2016, last review 2019. (http://www.iso.org/iso/catalogue_detail.htm?csnumber=61645).

[2] Network on Neutron Techniques Standarization for Structural Integrity, ***NeT network*** https://www.net-network.eu/ (accessed 28.12.2021).

[3] Vasileios Akrivos, Mike C. Smith, Ondrej Muransky, Carsten Ohms, Anastasios Youtsos, ***A residual stress measurement and numerical analysis round robin on a three-pass slot nickel-base repair weld – TG6***, January 202, Procedia Manufacturing 51:779-786, DOI: 10.1016/j.promfg.2020.10.109.

[4] V. Robin, D. Nélias, M Zain-Ul-Abdein, D. Maisonnette, E. Feulvarch, J.C. Roux, J.M. Bergheau, H. Hamdi, F. Valiorgue, T. Mabrouki, J. Bruchon, D. Pino Munoz, G. Kermouche, J. Xie, H. Walter-Le-Berre, Y. Ichikawa, K Ogawa, S. Drapier, ***Thermomechanical Industrial Processes - Modeling and Numerical Simulation – Chapeter 01***, iSTE Wiley Publishing, edited by J.M. Bergheau, Ecole Nationale d'Ingénieurs de Saint Etienne, France, 2014, ISBN 978-1-848213-58-6, pages 1-74.

[5] M. Rethmeier, M. Mochizuki, D. J. Dewees, V. Robin, C. Ohms, A. Youtsos, S. D. Smith, D. Schwark, ***CEN ISO/TS 18166:2015 – Numerical welding simulation – Execution and documentation,*** Mathematical Modeling of Weld Phenomena 11, Graz University of Technology Publishing, ISBN 978-3-85125-490-7, ISSN 2410-0544, 2015, pages 875-883.

[6] Vasileios Akrivos, ***Accurate Constitutive Behaviour for the Prediction of Weld Residual Stresses in Nickel-Based Alloy 600/82 Weldments Validated by Characterization Studies***, PhD thesis, University of Manchester, 2018. https://www.escholar.manchester.ac.uk/api/datastream?publicationPid=uk-ac-man-scw:313228&datastreamId=FULL-TEXT.PDF