International Journal of Pressure Vessels and Piping 86 (2009) 3–12

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

journal homepage: www.elsevier.com/locate/ijpvp

Robustness analyses of numerical simulation of fusion welding NeT-TG1 application: “Single weld-bead-on-plate”

Philippe Gilles [a,*], Walid El-Ahmar [b], Jean-François Jullien [b]

[a] AREVA, 92084 Paris La défense, France
[b] LaMCoS, INSA-LYON, CNRS UMR 5259, F69621, France

ARTICLE INFO

Article history:
Received 12 July 2007
Accepted 11 November 2008

Keywords:
Heat source modelling
Hardening model
Cyclic loads
316L austenitic stainless steel

ABSTRACT

This study contributes to the NeT-TG1 European Network formed in 2002. The aim of this study is to predict, by numerical simulation, the residual stresses generated in a test plate by the fusion welding process. The experiment consisted in the deposit of a weld bead along the longitudinal centre-line of an austenitic 316L plate using an automatic Tungsten Inert Gas (TIG) welding process with 316L filler material. During and after thermal cycle, a large quantity of measurement data is obtained that serve to develop a comparison with the results of different numerical models. The comparative thermal and mechanical analysis allows assessment for the general ability of the numerical models to describe the structural behaviour. The importance of the heat-input rate and material characteristics is also investigated. The residual stresses were predicted by the finite element method using the program Code_Aster of EDF and SYSWELD of ESI-GROUP. Finally the numerical results are validated by comparison with experimentally measured data.

1. Introduction

The numerical simulation of welding by the finite element method (FEM), made possible by the development of strong computing power, become a particularly interesting tool to predict residual stresses and distortions resulting from a welding process. Nevertheless, a reliable prediction of numerical welding simulation results remains very difficult, insofar as many complex phenomena intervene in the heat affected zone (HAZ). In order to carry out the numerical simulations with industrial computer FE codes, it is consequently current practice to neglect certain physical phenomena, to simplify the geometry or to reduce the dimension of the problem. Moreover, materials characteristic data and their temperature dependencies are not straightforward to obtain, especially for high temperatures. As a result, the level of accuracy of the numerical solution is difficult to control, when performing simulation of a complete welding operation.

The numerical welding simulation is considered to be one of those mechanical problems that have a high level of nonlinearity and which requires a good knowledge in various scientific fields (see Fig. 1). “Robustness Analysis” is a suitable tool to control the quality and guarantee the reliability of numerical welding results. An analysis of robustness can prove to be both computationally intensive and expensive making it an unjustifiable route. However, only with development of such analysis tool can predictive methods become a useful tool for industry.

The European Network on Neutron Techniques Standardization for Structural Integrity (NeT) aims to promote the use of neutron diffraction techniques. Several benchmark studies are proposed by NeT. The NeT-TG1 has the main objective to standardize residual stress measurement techniques on the benchmark, yet industrially valuable, case of a single weld-bead-on-plate problem and as such contributes to the overall NeT Network objective. On the other hand, TG1 aims at the equally important objective of validating the finite element method for simulating welding and predicting residual stresses, by comparing predicted results with measured data in the benchmark case of a single weld-bead-on-plate. This paper presents numerical simulations of the welding of the TG1 plate.

2. Definition of numerical welding robustness

The robustness of a welding numerical simulation is related to the sensitivity of the modelling assumptions to the input parameters. A simulation is known as robust if the result that it produces is not very sensitive to uncertainties in the input data [1].

The term “Robust” was coined in statistics by Box [2]. Various definitions of greater or lesser mathematical rigour are possible for the term, but in general, referring to a statistical estimator, it means “insensitive to small deviation from the idealized assumptions for which the estimator is optimized.” The word “small” can have two

* Corresponding author.
E-mail address: philippe.gilles@areva.com (P. Gilles).

0308-0161/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijpvp.2008.11.012

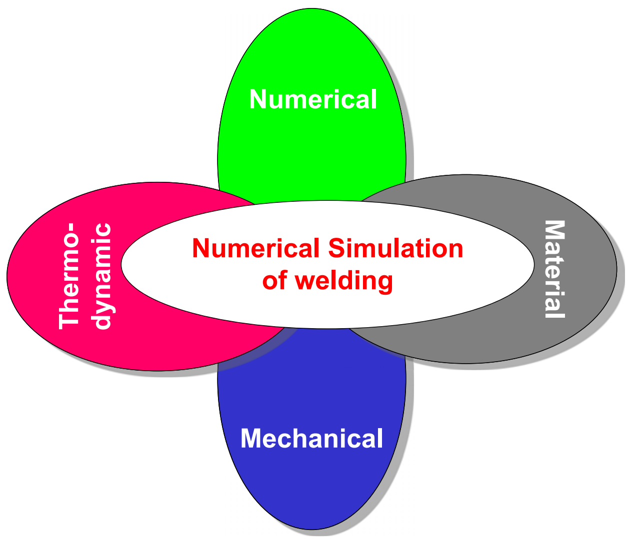

Fig. 1. Welding simulation fields.

different interpretations, both important: either fractionally small deviations for all data points, or else fractionally large deviations for a small number of data points.

The idea is to derive directive and scientific suggestions ensuring that different studies of a given welding simulation problem conducted by different engineers lead to similar numerical conclusions. With this prospect it is proposed to standardize the protocol of numerical welding simulation. So a method is needed to adapt the original definition of robustness to numerical welding simulation.

For the authors, robustness comes from pragmatic scientific planning, which is based essentially on the following four stages:

- Representative solution (R): the solution giving the best correlation between calculation and experience with the elaborate database.
- Sensitivity: to vary each parameter relative to its uncertainty level using a classical method (vary each parameter one by one; to check in which range of values, does R remain unchanged).
- Reliability: consistency/repeatability of the answers of the model.
- Standardizing: what kind of knowledge one must have for developing simplified methods and on the probable uncertainties in parameters that one is trying to use as input in FEM? This stage is of peculiar importance for industrial applications of the numerical welding simulation.

This paper addresses mainly the questions related to the first and last features of the robustness.

2.1. Planning of robustness study

During welding, several complex physical processes are taking place in a rather small area. The spatial variation of temperature in the weldment is quite high, generally up to several hundreds to thousands of degrees. This will generate many complex interactions between several phenomena.

To be able to study the robustness of a numerical result produced by a welding simulation it is necessary for us to reduce the complexity of the problem, by choosing a simple material, simple structure and the most adequate process.

2.1.1. The material choice

A material choice of type 316L stainless steel which is an austenitic stainless steel was made for this work. This steel has a stable austenitic matrix from the ambient temperature until its melting point, thus it does not have structural transformations in the HAZ during the welding process. By this choice of 316L material, the complexity of material interaction was reduced by a third as shown in Fig. 2.

2.1.2. The weld process choice

By the choosing of 316L steel, interactions in the HAZ were reduced to a thermo-mechanical coupling. Most of the numerical tools do not allow such calculations. However, for the selected Tungsten Inert Gas welding process, the assumption of an uncoupled thermo-mechanical calculation is relevant.

3. Theoretical welding physics

Areas of the workpiece close to the welding arc are heated up to several thousand degree Celsius, and then subsequently cooled down. The local heating and subsequent cooling induce volumetric changes producing transient and residual stresses and strains.

3.1. Thermal aspect

Tungsten arc Inert Gas welding, abbreviated as TIG or GTAW (USA), is an arc welding process that uses a non-consumable tungsten electrode and an inert gas shield to protect the electrode arc column and weld pool [3]. The TIG process conventionally uses direct polarity current with the electrode connected to the negative pole of the power source and base material to the positive pole as illustrated in Fig. 3. The TIG fusion welding process incorporates various complex physical processes such as heat transfer from the arc and droplets, the effect of arc pressure, and liquid convection in the deformed weld pool.

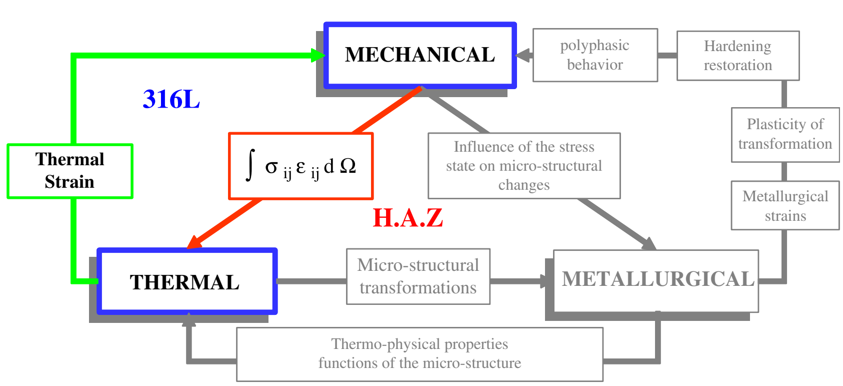

Fig. 2. Physical interaction in 316L HAZ.