Challenges in Numerical Simulation of Welding of Nuclear Components

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Welding problems encountered in the nuclear industry are not specific. Residual stresses present in reactors do not constitute a major problem at the design stage; however they may have a strong impact on some types of damage. Distortion may also be a source of concern in narrow gap welding or when the joined components are not fully restrained. Safety and economic issues make residual stress calculations important for integrity assessment, prediction of distortions attractive to comply with tolerance requirements, improvement of weld quality trough process simulation very appealing.

Growing interest in welding simulation

First thermomechanical models for welding simulation have been developed in the mid seventies. SYSWELD, the first software dedicated to Numerical Simulation of Welding is born in 1982. All the earliest studies in this field were dealing with the thermo-metallurgical-mechanical behaviour of the metal during welding. Simulations of the welding process itself have been developed in the 90s and application to industrial component started only 10 years ago. The automotive industry has been a leader in using welding simulation for the optimisation of part geometry, materials, and process parameters. The Naval research in USA, the nuclear industry in Germany and France have launched large R&D programs to improve welding of large components, but most of the effort concentrated on engineering & design problems.

AREVA R&D perspectives in welding simulation

AREVA aims to use numerical models for improving the whole chain of welding. Since more than 25 years, AREVA has spent large R&D efforts in welding stress simulation. Owing to efforts in material characterisation, development of tools and more efficient computing systems, the problem of predicting distortion has been addressed more recently. The new AREVA perspective is to extent our efforts in three domains:

- Mechanics, metallurgy and damage analysis for a better mastering of weld repair techniques.
- Development of methods and tools for the non-expert in numerical simulation. On one hand engineers need to compute stress fields and their effect on fatigue, fracture or corrosion in large components. On the other hand, welders are interested in reducing the number of weld process qualification mock-ups, minimizing the amplitude of distortion for a better controllability of welds trough numerical simulation.
- Arc and weld pool modelling for the improvement of weld penetration, control of weld pool shape, mitigation of weld defects.

The paper presents through practical cases some of these challenging tasks in Numerical Welding Simulation AREVA decided to tackle.
As an example of these difficulties, we illustrate below the effect of metallurgical phenomena on the residual stress predictions in a Dissimilar Material Weld.

AREVA analyses on the weight of metallurgical phenomena on residual stress fields in a Dissimilar Material Weld
In the frame of the European Community research BIMET and ADIMEW programmes residual stress have been measured on a stainless steel/ferritic steel bimetallic weld using the neutron diffraction technique across the piping thickness in the buttering, weld and the HAZ of the base material. No Post Weld Heat Treatment has been applied to the BIMET mock-up, but for nuclear plants these DMWs are heat treated in a furnace after welding as it is the case for the ADIMEW mock-up.

AREVA NP and ESI have analyzed in detail the sensitivity of the predictions to the material behavior modeling. Four issues have been analyzed:

1. Influence of the characterization of weld metal tensile properties
2. Type of cyclic strain hardening behavior
3. Strain hardening recovery effects
4. PWHT stress relief effects.

The following figure illustrates the dilution of the base metal in the weld beads: the limit of the diluted zone is marked by the line showing the initial ferritic: buttering interface. The fusion line is at about 1 mm from this initial interface and the Heat Affected Zone extends over 2.7 mm in the ferritic metal.

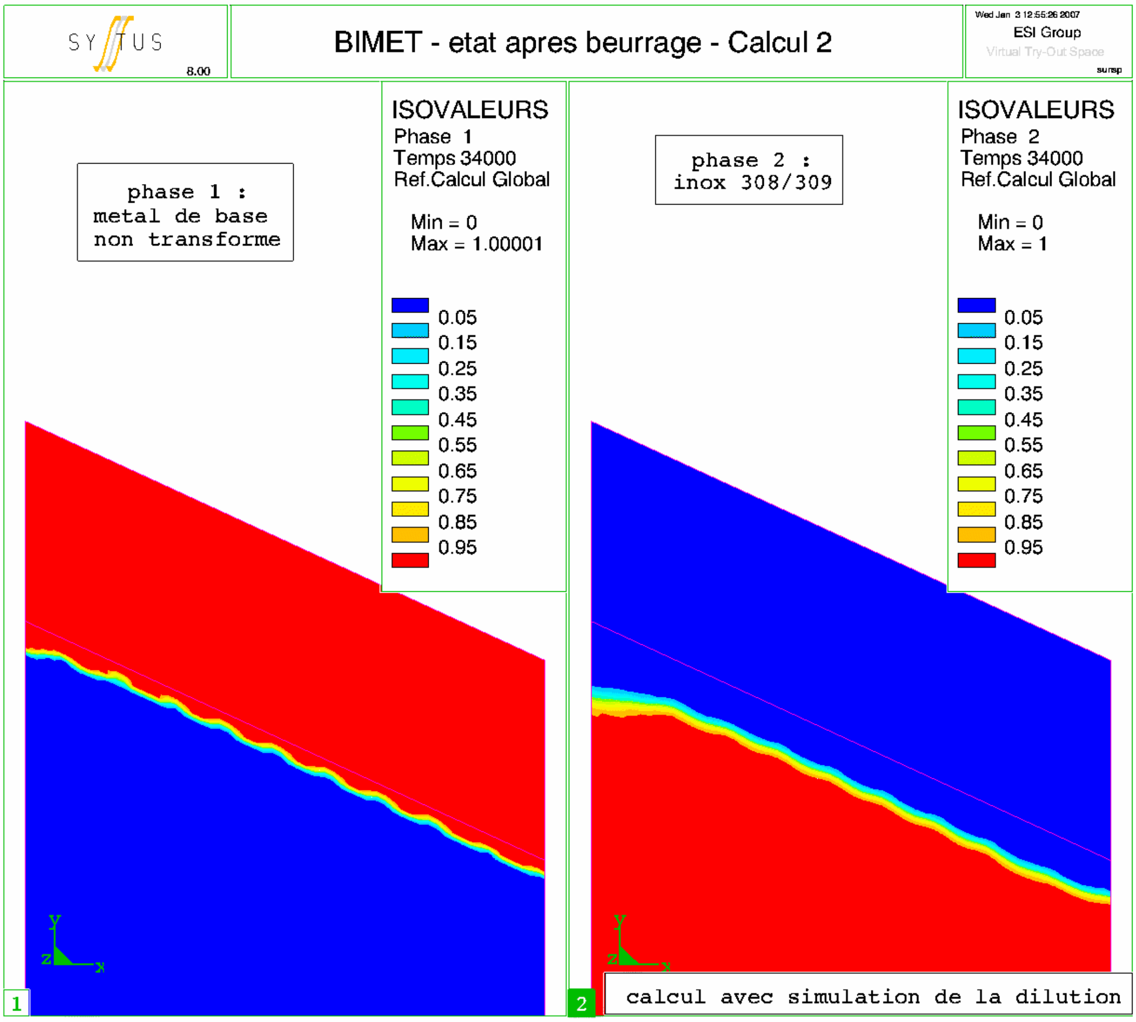

Figure 1 – Metallurgical state in the vicinity of the buttering- ferritic interface: on the left without transformation and on the right including dilution effects

The paper concludes on the expected impact of progress in these domains of Numerical Welding Simulation and the R&D perspectives in AREVA on these topics.