Case Study: **The Institute for Logistics and Production Engineering (BAY-LOGI)**

Marc Simulates Welding of Nuclear Pressure Vessel Reactor Nozzles

Overview

The reactor pressure vessels make up the heart of a nuclear power plant, containing the core, core shroud and coolant. In water-cooled water-moderated energy reactors type power plants, nozzles on the ferritic steel pressure vessel are welded to primary coolant pipes made of austenitic steel. These nuclear power plants were built and started operating 20 to 30 years ago. The company operating one of these power plants needed to know how these welds can be expected to perform after a long period of service. It's not practical to perform measurements on the reactor itself because of the complex geometry and the presence of radiation. Building and testing a duplicate structure would be expensive and it would also be very hard to replicate the effects of 20-plus years of operation. So the operator of the power plant agreed with the Department of Structural Integrity at Bay Zoltan Institute for Logistics and Production Engineering (BAY-LOGI) to simulate the manufacturing process to better understand the characteristics of the welded joint.

Figure 1: The reactor pressure vessel with the nozzle ends

“The simulation results helped us understand more deeply the nature of the welded joint and the safety margins for long term operation.”

Zoltan Bezi, Research Fellow, BAY-LOGI

Challenge

The most relevant results of the heterogeneous welding simulation are distortion effects as well as residual stress and strain distributions. By the use of local approaches it is therefore possible to incorporate mean stress effects into local fatigue life assessments. Since the stresses can increase above the yield stress of the material, plastic deformation has to be taken into consideration. So it is important to select a material model containing the appropriate strain hardening law reflecting the local properties to calculate plastic strains and stresses. Additional complications include the multiple materials involved, phase transformation, large deformations and large size of the welds. Due to the complexity of this simulation several models are needed so the last main challenge was the transfer of residual stress and displacement fields between the different models and mesh types.

Solution/Validation

MSC Software’s Marc Nonlinear FEA software was selected because of BAY-LOGI engineers’ experience with similar problems that Marc solved successfully and achieved very good correlation with physical experiments. The material model for heterogeneous welding was selected by utilizing BAY-LOGI engineers’ experience from an earlier modeling problem, where the task was to simulate repair welding on an austenitic stainless steel pipe of another type of reactor.

In that case the original weld state had to be modelled and its results had to be taken into consideration during the repair welding simulation. It was performed in three different steps. First the girth welding of the pipe was performed on simplified geometries to decrease the calculation time. The simulation of the machining of the weld was also performed in one step. The last task was the simulation of the repair welding operation. This simulation also required multiple models due to its complexity so the method developed to transfer results between any given pre-defined finite element meshes in the different models was adopted for the heterogeneous case. Basically a loadcase was created to read the stress and strain distribution from the previous model while re-meshing the model by utilizing an existing mesh. This new mesh consisted of tetrahedral elements while the original model was built from hexahedral elements.

The results showed that repair welding can be simulated most precisely by using the Chaboche combined hardening material model. The validity of the Chaboche model was verified before it was applied to the simulation of the reactor nozzle.

Key Highlights:

Product: Marc

Industry: Nuclear

Benefits:

- Model coupled thermo-mechanical effects of multi-pass welding process
- Gain insight into residual stress distributions
- Save on costly physical testing

The verification was done by a mock-up welding simulation. An assumption was made that it is satisfactory for the simulation of heterogeneous welding as well.

The mock-up welding model consisted of a heterogeneous joint of 40 mm thick plates. The material properties of this model were identical to the material properties of the reactor nozzle and the coolant pipe. The material model with phase transformation was verified during the simulation of the welding of the buttering and cladding layers on the plate. The heterogeneous mock-up

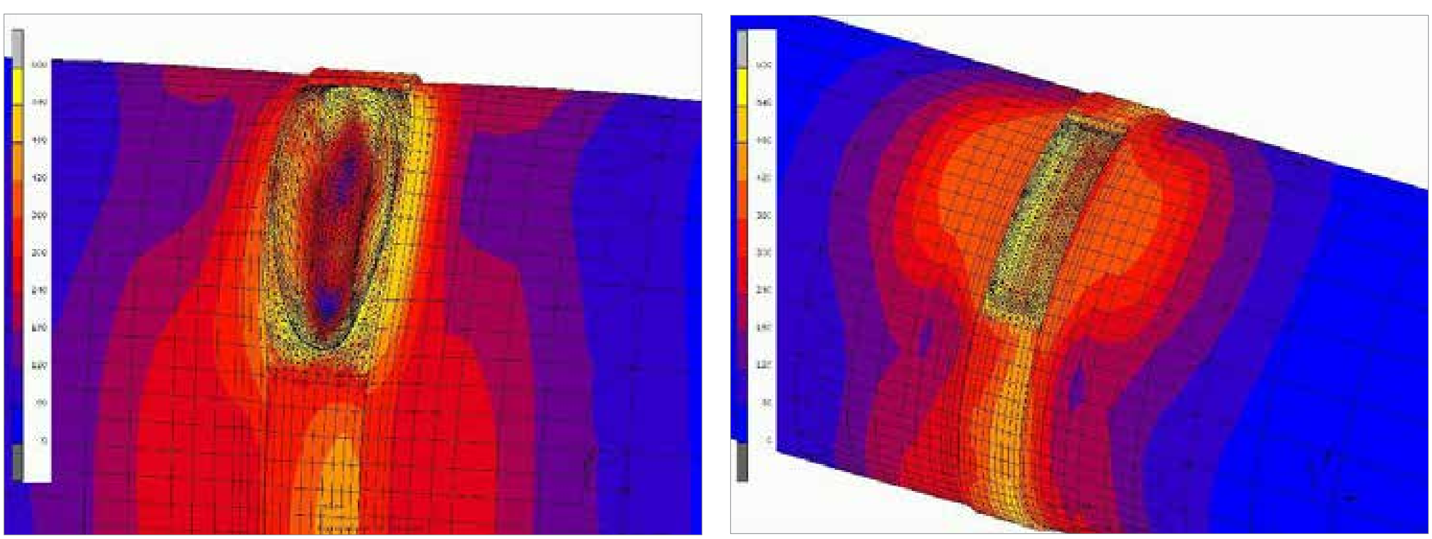

Figure 1: Residual stress distribution: left – after girth welding and machining, right – after repair welding

joint was welded with 39 passes. “The resulting stress distributions showed good agreement with the experimental results captured on a small scale mock-up,” said Zoltan Bezi, Research Fellow for BAY-LOGI.

Based on this experience, the heterogeneous welding of safety end nozzle was modeled in 3D. The joint was built from 98 weld runs. The model consists of more than 400,000 hex elements. The task was solved in approximately 18,000 nonlinear increments. “Based on the promising verification we believe the calculated stress state of the dissimilar metal weld is a good representation of the as-welded state.” Bezi said.

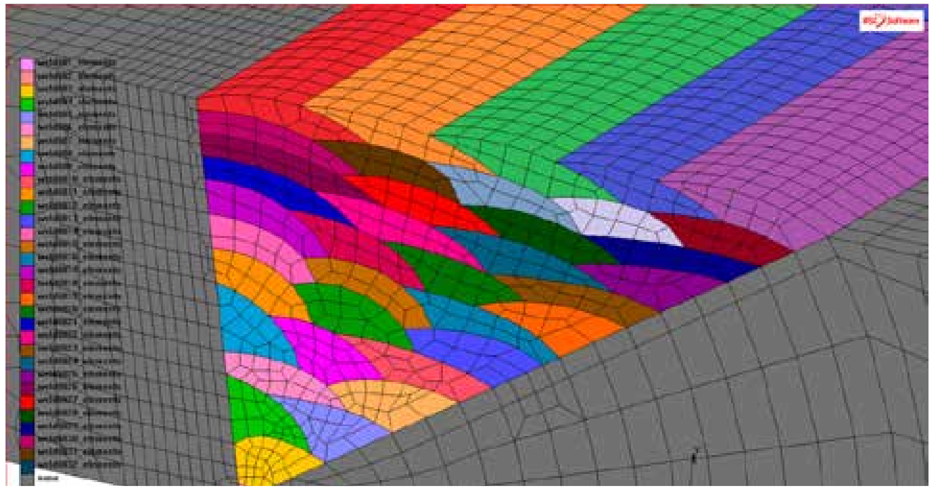

Figure 2: Simulation of the mock-up welding

Results

“The simulation results helped us understand more deeply the nature of the welded joint and the safety margins for long term operation,” Bezi said. “By applying case specific FE simulations, the weld and its residual stresses were realistically assessed. The properties of the weld and heat affected zone including the temperature distribution and residual stress distribution were also determined and these values were used for the subsequent structural integrity assessment. With FE, the effect of ageing and operational loading on the stress state of welds was also taken into account. This made it possible to investigate the long term operational effects. The end result demonstrated that the welding simulation provides the necessary information about the initial stage of the joint so we could be certain about long term safe operation without having to build a duplicate structure, saving millions of dollars.”

About BAY-LOGI

Bay Zoltan Institute for Logistics and Production Engineering (BAY-LOGI) is the leading applied research organization in northern-Hungary. The BAY-LOGI Department of Structural Integrity examines damage processes of structural materials, analyzes the reliability of failure detection methods, assesses the condition and the lifetime of structures and estimates the remaining lifetime. The department has participated in lifetime extension projects at nuclear power plant and in related international projects under the EURATOM umbrella.

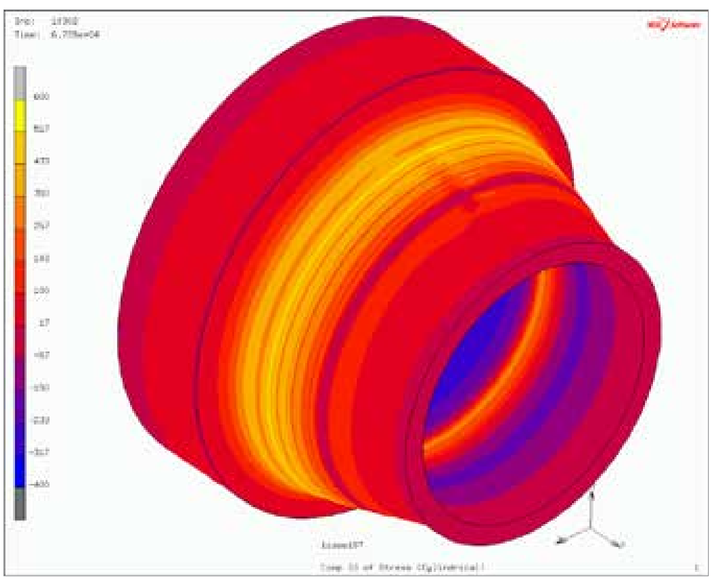

Figure 4: Axial stress distribution

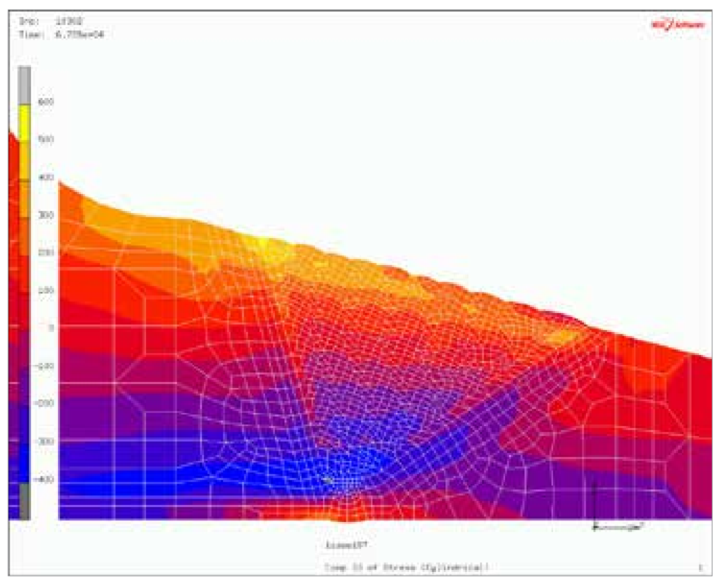

Figure 5: Axial stress distribution along the wall thickness

For more information on Marc and for additional Case Studies, please visit **www.mscsoftware.com/marc**

Corporate
MSC Software Corporation
4675 MacArthur Court
Suite 900
Newport Beach, CA 92660
Telephone 714.540.8900
www.mscsoftware.com

Europe, Middle East, Africa
MSC Software GmbH
Am Moosfeld 13
81829 Munich, Germany
Telephone 49.89.431.98.70

Japan
MSC Software LTD.
Shinjuku First West 8F
23-7 Nishi Shinjuku
1-Chome, Shinjuku-Ku
Tokyo, Japan 160-0023
Telephone 81.3.6911.1200

Asia-Pacific
MSC Software (S) Pte. Ltd.
100 Beach Road
#16-05 Shaw Towers
Singapore 189702
Telephone 65.6272.0082

BAYLOGI*2014NOV*CS