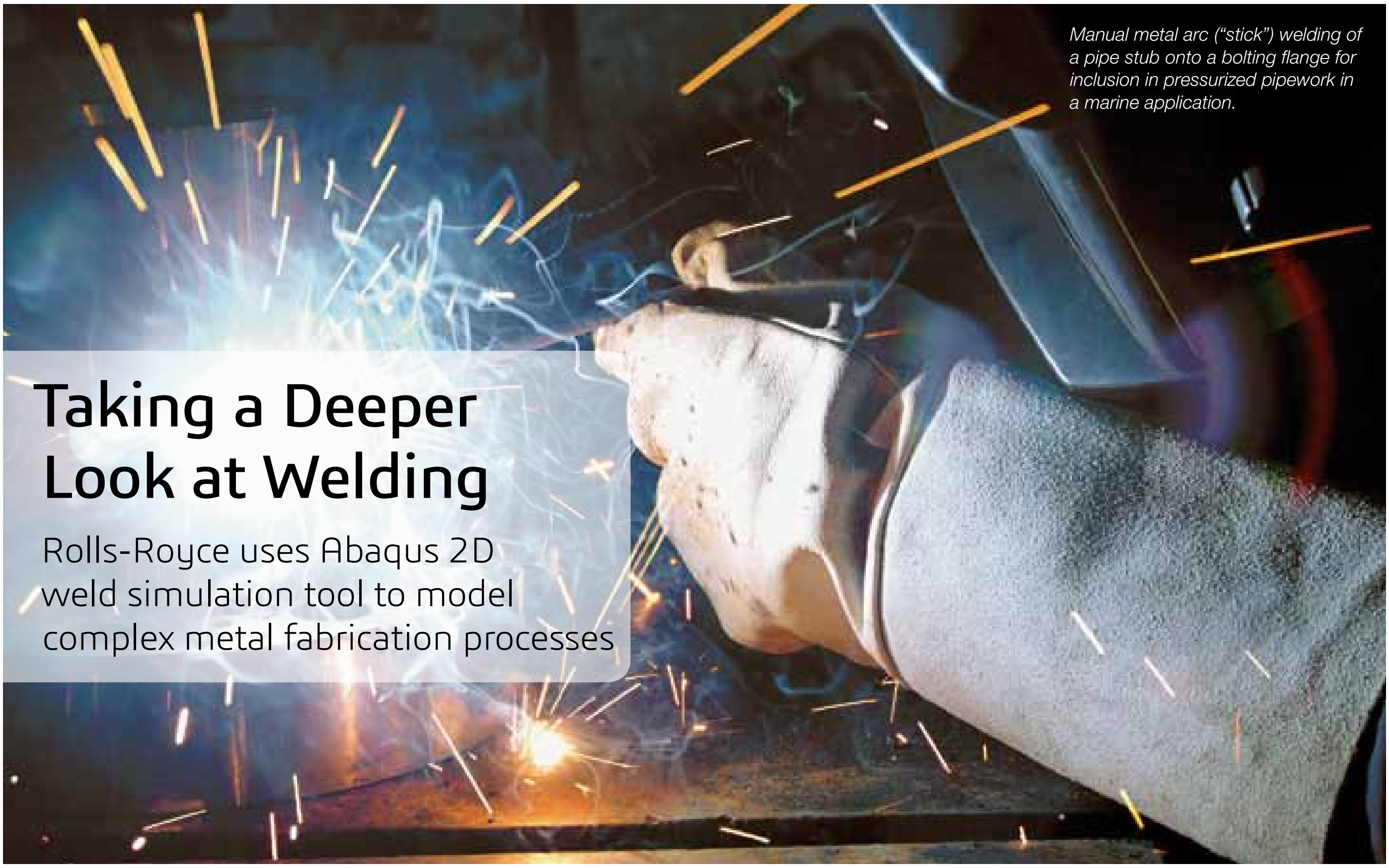
Taking a Deeper Look at Welding

Rolls-Royce uses Abaqus 2D weld simulation tool to model complex metal fabrication processes



Manual metal arc ("stick") welding of a pipe stub onto a bolting flange for inclusion in pressurized pipework in a marine application.

The idea of joining metals together dates back to the Bronze Age. Forge welding advanced in the Middle Ages, when village blacksmiths hammered heated metal until bonding occurred. The discovery of the electric arc in the 19th century sparked the development of many welding techniques in use today, with advances in electron beams and lasers further refining the technology in more recent decades.

Many industries—including shipbuilding, aerospace, defense, offshore energy, automotive, and nuclear—continue to rely heavily on welding to build their core products (a single automobile can contain 5,000 to 10,000 welds). Yet the practice of welding is still considered to be more "art" than "science," highly dependent on the skill and competence of the individual welder, or the quality of robotic welder programming.

In a process that involves high temperatures, material phase transformation, and the deposition of material, it's a challenge to produce the perfect weld every time. So engineers are looking for ways to study and predict the effects of different welding techniques on the behavior of the materials being fused. This knowledge can help avoid design guesswork, speed up the product development process, and contribute to higher quality of finished products. What's more, by identifying the best welding methodologies, the information can be incorporated into improving the training of human welders, and the programming of robotic ones as well.

Autogenously welded plate sample

Realistic simulation deepens knowledge of welding process

Realistic simulation with finite element analysis (FEA) is a key tool for the design engineers in Rolls-Royce's Marine division, who are currently quantifying and verifying the many parameters involved in welds used in marine power plants and propulsion. "Welds are a complex modeling problem requiring both thermal and structural solutions," says David Hodgson, stress engineer, primary components, Rolls-Royce (Derby, U.K.). "We are looking to predict the distortion of components during manufacture, the position and magnitude of peak residual stresses, and the effects of the welding process on the metals involved."

Hodgson's group has an ongoing research partnership with the Materials Science Center of The University of Manchester, and Serco Assurance. Rolls-Royce has been evaluating several FEA packages for years, including SYSWELD, VFT, and Abaqus FEA from SIMULIA, the Dassault Systèmes brand for realistic simulation. Recently, as part of their strategy to improve their capabilities to accurately perform weld analysis, the company added the Abaqus Welding Interface (AWI). An extension to Abaqus/CAE, the product streamlines the generation of two-dimensional welding simulations by providing a graphical user interface (GUI) for defining all aspects of the weld model such as weld beads, weld passes, film loads, and radiation loads.“The weld simulation tool is helpful because it allows us to carry out further analysis of both thermal and structural models directly within the Abaqus unified FEA environment,” says Hodgson. “This has helped us reduce data translation issues, training time and expense.”

Simulation goes under the torch

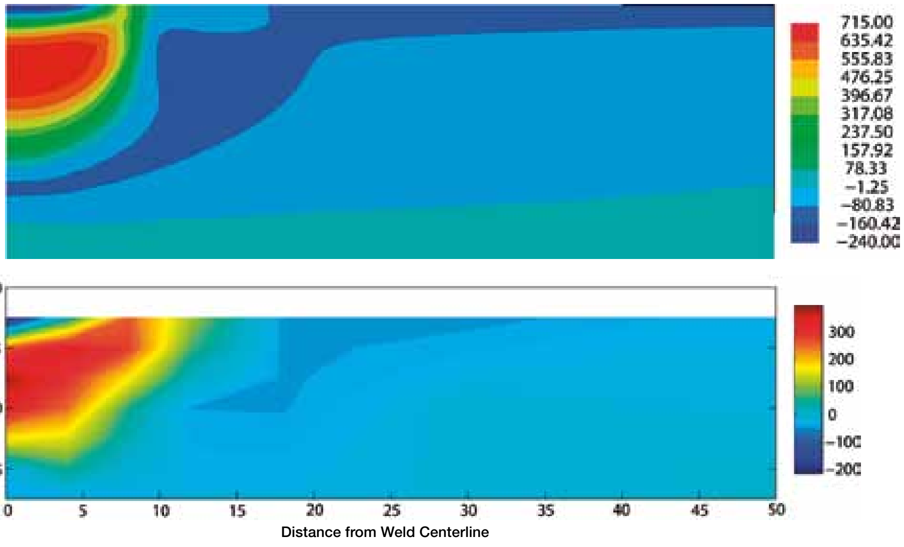
The research team decided to use the AWI tool to examine three different welding scenarios: autogenously (self-material) welded plates, an eight-pass groove-welded plate and a seven-pass ring weld disk. The autogenously welded plate model simulated a single plate of pressure-vessel steel melted by one or two passes of a welding torch. The more complex eight-pass and ring-weld steel models involved multiple torch passes and a ferritic steel filler material—which might be used in an offshore oil installation, or a nuclear reactor. Both quadrilateral and triangular heat transfer elements were used for the thermal models, while a generalized plane strain model was used for the structural analysis.

Applied heat, and the metal’s structural response to that heat, are intimately intertwined in the welding process. But from the simulation point of view, each of these separate parameters needs to be defined so they can be included in a multiphysics analysis of their coupled interaction. Through the AWI, the temperature history calculated in the thermal model provides the temperature input (i.e. the load) for the structural model. This allows the structural model to analyze the thermal expansion and contraction of the metals being welded that result from changes to the materials’ mechanical properties.

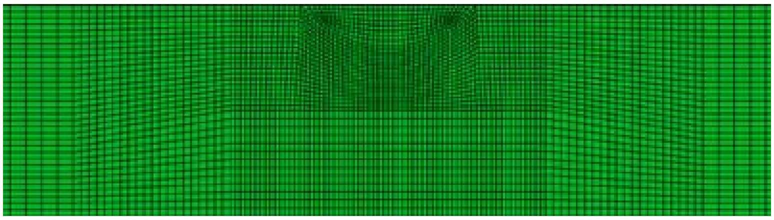
Automating surface definitions speeds up modeling

To set up such a model, the AWI imports a basic meshed part (with no boundary conditions, loads or interactions) with its materials and sections defined, and allows the user to create weld beads along the area to be welded. The modeler then automatically defines weld passes based on the weld bead order, and assigns surface film and radiation heat-transfer properties.

“One of the most time-consuming aspects of weld modeling is the surface definitions for heat transfer coefficients,” says Hodgson. “These definitions have to be constantly updated as the weld build-up modeling progresses. The automation of this by the AWI helps speed the process considerably.”



FEA image (top) and Neutron diffraction (bottom) stress measurements in one-pass test sample.



FEA model of autogenously welded plate

The method used for controlling the heat flux within the thermal model involves setting a fusion boundary: Sensor nodes within the mesh, defined at specific depths, are used to end the heating step when their average temperature reaches a predetermined limit (1500 degrees Celsius in this case).

Real-world welding shows stress results

To verify their models against real-world results, the engineering team created small welding test specimens of the pressure-vessel steel and measured the residual stresses after passes by a mechanized Tungsten Inert Gas welding head. The measurement process involved neutron diffraction (ND), which (in a manner similar to X-rays) involves placing a sample in a beam of neutrons and recording the diffraction intensity pattern that results from changes in the structure of the crystalline solids in the steel. The pattern records the crystal lattice spacing within the steel that can be compared with a stress-free spacing value to calculate a strain measurement. This strain measurement can then be used to infer the stress present within the metal.

The autogenously welded FEA models were compared with the ND test results and the one-pass results showed a particularly close correlation. Work continues on refining the more complex models for accurate simulation of the many intertwined processes involved in welding. “The 2D weld modeling interface is a useful tool to combine with Abaqus/CAE,” says Hodgson. “Its evolution into a full 3D moving heat source is desirable and should be conducted in conjunction with advanced weld material modeling tools.”

For More Information

www.rolls-royce.com/marine
www.simulia.com/products/welding