Full Speed Ahead on Welding Analysis

Simulation enables shipbuilders to automate welding procedures – saving time and money.

by **Heeyoung Heo**

Competition in the worldwide shipbuilding industry is fierce. That is why shipbuilders are constantly searching for innovative ways to eliminate inefficiencies, improve quality, boost productivity and cut costs to stay afloat.

Samsung Heavy Industries (SHI) Co. Ltd., part of the Samsung Group, is a Korean shipbuilder well aware of global business challenges. The company's Shipbuilding & Offshore Division specializes in commercial and value-added ships, offshore vessels and structures, and cargo and material-handling facilities.

To keep its position as a leader in the industry, SHI proactively pursues cutting-edge technology in product design and development. In manufacturing, for example, SHI recently implemented a computer-aided analysis system that enables shipbuilding engineers to quickly simulate and minimize welding-induced distortion and shrinkage. Analysis results are used to control hull panel weld distortion in the design and production planning stages so that SHI can make rapid decisions for modifying welding procedures or fabrication methods.

Welding is a complex thermo-mechanical process that is difficult to simulate analytically. In most cases, the experience of seasoned welding engineers is used to control the effects of the welding process so that distortions and shrinkage can be managed effectively. Even with this experience, most large welded struc-

Quality weldments of thick plates (greater than 10 mm) are paramount to fabricating hull structures to withstand the rigors of oceanic shipping.

tures rely on complicated fixtures and jigs and significant rework to produce a structure with the right shape and strength to meet the design requirements.

In Ship Shape

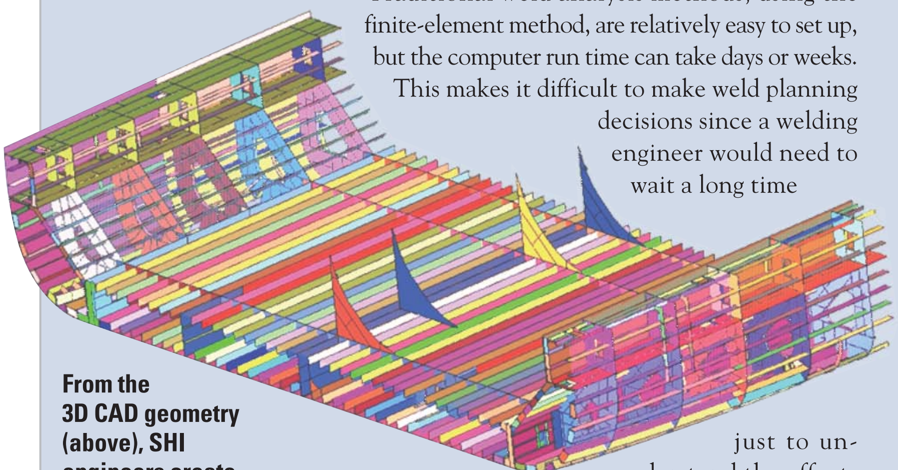
Super-large containerships, liquid natural gas carriers, Arctic shuttle tankers and drill ships are among the vessels that SHI builds in Korea. The cutting and welding of thick plates (greater than 10 mm) are paramount to their fabrication. However, the process inherently involves thermal deformation and shrinkage.

Weld distortion and shrinkage occur due to the large thermal gradients induced during welding. In the weld zone, the metal is molten, and as it cools, it shrinks. The surrounding metal is rigid and resists this shrinkage. As a result, many complex mechanical loads are generated in the structure to balance the thermal loads, leading to warpage, distortion and shrinkage of the structure. If you were to throw a piece of aluminum foil in a campfire, you would notice that it would distort and change shape as it heats up. This is due to the same principle wherein the temperature differences in the foil cause mechanical loads that deform the foil.

In general, warpage, or out-of-plane deformation, is typically fixed during assembly using a jig and after assembly using thermal or mechanical rework. Thermal rework is using a heat source, such as a torch, to deform the overall structure to the proper shape.

Mechanical rework uses jigs or other mechanical forces to deform the as-welded structure to the proper shape. Both processes can be time-consuming and usually require expert technicians with years of experience. In-plane deformation, or shrinkage, cannot be easily fixed during assembly and needs to be corrected prior to assembly.

Traditional weld analysis methods, using the finite-element method, are relatively easy to set up, but the computer run time can take days or weeks. This makes it difficult to make weld planning decisions since a welding engineer would need to wait a long time just to understand the effects of different weld sequences, fixturing or the welding process. As a result, weld engineers typically rely on experience and engineering judgment.



From the 3D CAD geometry (above), SHI engineers create quality meshes using Altair HyperMesh (right).

Over the years, researchers have developed some simplified analysis methods that can more quickly predict weld-induced shrinkage and distortion. These methods make several simplified assumptions but are able to accurately predict shrinkage and distortion trends and can be used to better plan welding processes. These models run quickly (in minutes vs. days) and can provide rapid feedback to the welding engineer that helps him/her better understand the effects of welding on the overall structure.

The challenge with these methods is that the setup of the model can be time-consuming and subject to mistakes if done manually.

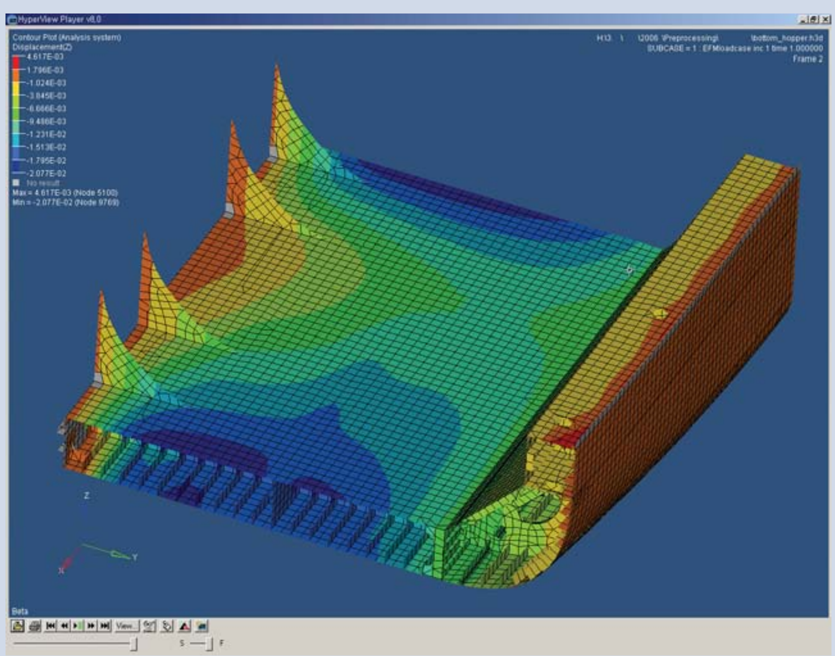
SHI, working with Altair Engineering, developed a semi-automated analysis setup system that can generate and run models in a few hours. Weld analysis can now be used to positively affect the business of SHI. This pre-processor enables the company to quickly predict the effect of the weld process and fixturing on the final shape of the welded ship structure.

The system automatically creates the FEA model from the geometry and property information imported from the computer-aided design (CAD) model. This FEA model, in turn, is used to predict the weld shrinkage and distortion based on the type of weld joints, welding process and plate thickness of the weld region. This is all done with a user-friendly interface that ensures consistency and flexibility.

Macro Power

The customized welding deformation analysis pre-processor was built as a series of macros inside the Altair HyperMesh pre-processor, a solver-neutral environment with a rich feature set to build and edit computer-aided engineering (CAE) models. The tailored HyperMesh pre-processing system interfaces directly to SHI's specialized 3D CAD software and FEA solvers.

With this solution, engineers extract 3D geometry and property information as ACIS and text files, respectively. Meshing and surface editing tools allow



engineers to easily cut and join geometric surfaces to create quality meshes critical for analysis. The thickness of the plates is extracted from the 3D geometry and property files.

The user can define the type of weld for each region (e.g., butt-weld, fillet weld, etc.), the weld process and sequence, and the weld dimensions. The system then generates the models with all of the appropriate boundary conditions and input for an accurate, repeatable analysis. Given that the system is hosted in HyperMesh, the user has the flexibility to edit any regions that are not set up properly in unique situations.

Previously, SHI used another pre-processor. However, it lacked the capabilities to successfully import geometrically correct ACIS files. HyperMesh's open architecture allowed Altair engineers to develop custom integrations with the CAD and FE solvers used by SHI.

A Way with Welding

Altair engineers worked closely with SHI to automate the weld distortion analysis process. Over several months, they developed a core program and graphical user interface specific to SHI's needs.

They also suggested proper 3D CAD import methods and offered implementation details based on weld deformation analysis algorithms (see *Algorithms for Weld Distortion Analysis*) and other boundary conditions. In addition, they customized the solver analysis template to comply with SHI's request.

With the solution completed, SHI engineers were able to evaluate welds by following three easy steps: establishing the user profile, defining and selecting the process, and running the analysis.

The User Profile: Altair developed a new user profile under the existing menu structure. A simple click of a radio button calls up the Macro Menu.

The Process: Upon clicking the SHI radio button, the Instance Manager window opens and shows three main function buttons: New Instance, Open Instance and Use Default HyperMesh. In the case of the Open Instance, all data-like parameters applied during previous sessions remain. Information is recorded into the metadata of the HyperMesh model files.

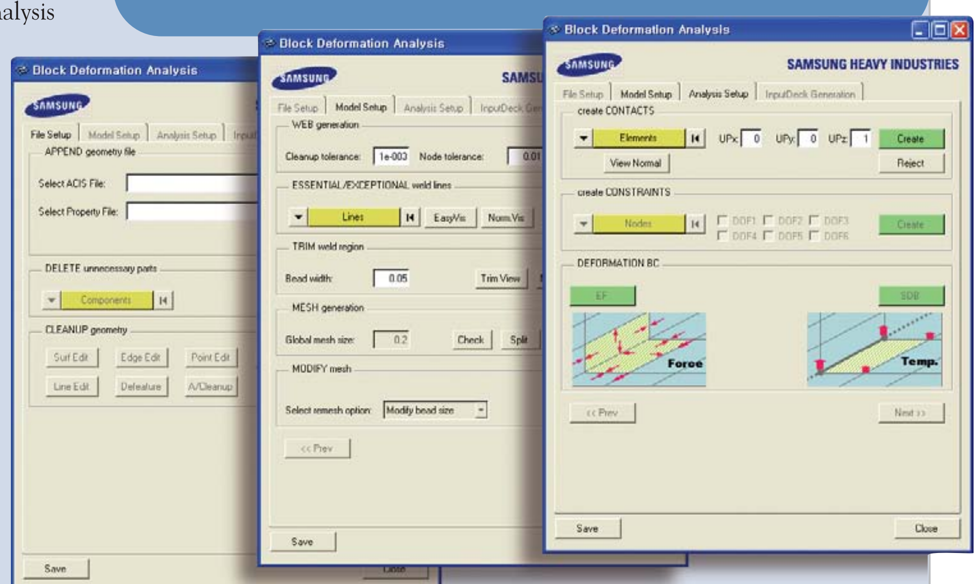
Algorithms for Weld Distortion Analysis

Currently, there are two simplified methodologies used for weld distortion analysis. The first is the Equivalent Load Method, or ELM, and the second is the Strain as Direct Boundary (SDB) method.

The ELM technique adds equivalent mechanical loads on the finite-element nodes and elements in the analysis model to simulate the thermal loads induced after welding. For example, in-plane loads on the boundary edges of the element adjacent to the weld line are added to capture thermal shrink behavior after butt-welding. Although this method is well-known in weld distortion simulation, applying the loads on the proper domain with the proper value and direction is a relatively time-consuming process and subject to errors if not done in an automated, repeatable manner.

The SDB method describes weld distortion by thermal contraction through the equivalent thermal expansion coefficient and equivalent temperature difference applied around the weld region. If the heat coefficient is negative or the temperature difference is negative, then the shrink behavior at the weld line after welding is well-captured. The SDB method is relatively easy in that it adds temperature on the selected nodes, but the theory is slightly tricky. The SDB method allows weld sequence to be modeled, which can be important in determining the final distorted shape of the structure. This also allows users to understand the effects of different weld sequences virtually.

In the analysis process, finite elements are generated on existing and newly created surfaces. The ELM method requires one special layer of perpendicular quad elements to add perpendicular theoretical loads, like forces and moments, on the node. The SDB method requires two special layers near the weld line to add temperatures on the nodes between elements of the two layers.



Innovation in Action

Samsung Heavy Industries (SHI), with eight worldwide branch offices and two manufacturing subsidiaries, is part of Korea's Samsung Group. In 2007, SHI received a record number of orders, surpassing the US$10 billion mark during the first half of the year – a milestone among Korean shipbuilders. SHI maintains the world's No. 1 market share in high value-added vessels and has installed the world's largest offshore facilities off Sakhalin.

In November 2007, SHI delivered to Stena, a Swedish ship company, the world's first drill ship designed to operate in polar regions. The ship is 228 meters long, 42 meters wide and 19 meters high. It can drill as deep as 11 kilometers and operates in severe weather conditions, including waves of up to 16 meters and wind speeds of up to 41 meters per second.

SHI also is a leader in building super-large liquid natural gas (LNG) tankers. It recently delivered the largest LNG ship in the world, christened TEMBEK, to Qatar Gas. The ship is 217,000 m^2 in volume, 303 meters long, 50 meters wide and 27 meters high. Unlike traditional LNG ships that use steam turbine engines, the TEMBEK runs on a low-speed diesel engine.

The definition phase involves building the FE model by generating finite elements, creating the boundary and load conditions, and defining control cards. Two files are used for generating the shape geometry. The first, Geometry Files, includes the surface entity of the initial plate and the line entity of the weld line. The second, Property Files, includes the thickness and material of the plate, type of weld line, shape and material information on structural stiffeners.

What makes the solution unique is that the two files are imported into HyperMesh simultaneously, and the proper properties of surfaces and lines are automatically created. In addition, the geometry of the structural stiffeners from the lines is created, and geometry editing at the weld region for proper welding analysis is performed.

Next, welding boundary conditions are applied. Then, load cases are created and applied automatically, and the contact definition and the boundary condition used during analysis are properly made.

Solver: The system generates an input deck for the solver. It includes all options required for running the analysis and is exported without any further debugging.

Being able to virtually simulate the weld deformation analysis process has made a difference at SHI. Prior to installation, it was impossible to qualitatively predict the weld distortion of complex parts.

In addition, what used to take 40 hours of manual labor for structural modeling has been reduced to two to three hours for the entire process. And, human errors have been reduced, resulting in cost savings. What's more, the system provides visualization of the hidden regions of the welded parts, which may not have been considered if it were not for the simulation.

The developed weld analysis system is providing significant benefits to SHI. Engineers can now quickly analyze the effects of different weld processes, fixturing, sequencing and postweld rework operations on the final structure. This is resulting in fewer "surprises" that affect rework and other downstream processes and provides more efficient welding processes and better quality ships. It also creates a consistent framework for implementing weld distortion and shrinkage analysis processes throughout the enterprise, which means the tools are accessible to more engineers and just not the FEA experts. C2R

Heeyoung Heo is Senior Research Engineer, Welding Research, Institute of Industrial Technology, Samsung Heavy Industries. **Robert Yancey,** Regional Managing Director, Altair Engineering, Inc., was a contributor to this article.

To receive more information about HyperMesh, visit *www.altair.com/c2r* or check 02 on the reply card.