Abaqus Welding Interface (AWI) - Isight integration for optimum weld-sequencing

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Abstract: *Pipe joining by welding is a widely used process across many industries, including nuclear, pressure vessels, piping and oil & gas. The ability to accurately determine the residual stresses in a pipe joint is important for cost effective operation of plants. Weld sequence and direction plays important role in pipe welding process which has direct impact on residual stresses along with geometry of structure, weld material, type of weld joint, torch speed etc. The objective of this work is to identify the optimum weld sequence that results in minimum residual stresses.*

The application of Abaqus Welding Interface (AWI) to model multi pass welding of a stainless steel pipe joint is presented, demonstrating the integration of Isight and AWI to obtain optimum weld-sequencing for minimum residual stress distribution. Multi pass weld sequences exponentially increase the number of possible combinations making it practically impossible to prototype. AWI and Isight integration addresses this challenge effectively and eliminates the need for costly prototyping.

Keywords: *Design Optimization, Residual Stress, Seam Welding, Abaqus Welding Interface (AWI), Isight*

1. Introduction

The residual stresses from welding increase the weld joints' vulnerability to fracture, fatigue failure and stress corrosion cracking. The residual stresses have a complex dependency on many variables, including the geometry of the structure, properties of the base and weld materials, the weld pass sequencing (in multi-pass welding scenarios), inter-pass temperatures employed, the boundary constraints on the part being welded, and the energy input from the welding. To arrive at the process parameters that result in minimum residual stress involves testing with lot of prototyping and is time consuming as well as expensive.

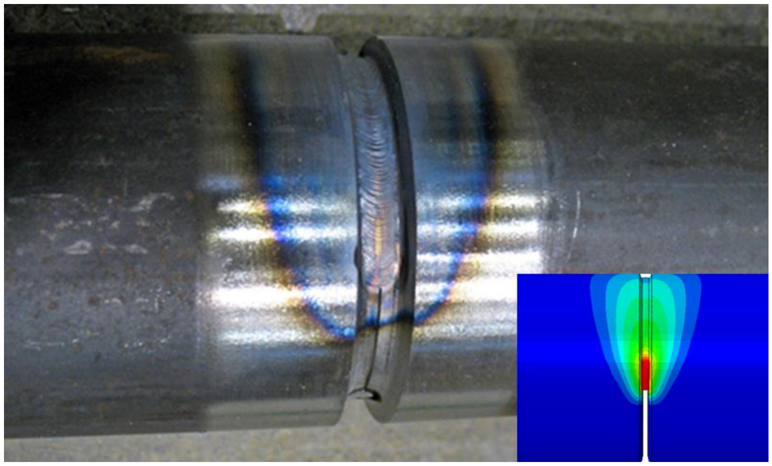

Figure 1. Pipe Welded Joint [6]

Abaqus Welding Interface (AWI) [3] is an add-on to Abaqus/CAE that facilitates easy setup of welding simulation models, and integrates seamlessly with Abaqus solver. Isight, a process integration and design optimization (PIDO) tool with its Design of Experiments (DOE) techniques can leverage the benefits of setting parameter values in a set of experiments and execute the simulation process flow.

While Abaqus is widely used in welding simulations, the model setup is challenging for multi-pass welding application as it should account for the evolving geometry due to bead material deposition from welding, which affects aspects such as film interactions, loads and/or boundary conditions and these have to be defined over a large number of analysis steps. AWI automates most of the time consuming steps associated with the welding model setup, saving valuable analyst time.

The current study demonstrates the integration between AWI and Isight to obtain optimum weld-sequencing for minimum residual stress distribution. AWI and Isight integration can eliminate the need for costly prototyping.

2. Modeling with AWI

AWI is used to create the heat transfer and stress analysis models for a 3-D pipe geometry. The pipe segments being welded are each 400 mm long, with an outer diameter of 114.3 mm and thickness of 6 mm. The geometry of the pipe as well as the thermo-physical and mechanical properties of the base metal (SUS304) are taken from [2]. The weld metal properties are assumed to be the same as that of base material. An element-based chunking option is used, with each bead subdivided into 21 element-based chunks (each chunk spanning approximately 17º) in the circumferential direction. A target torch temperature of 1500 ºC is used as heat input from the welding source. A torch step time of 11.6 seconds was estimated for each chunk based on the chunk size and the welding speed. AWI generates pre-defined temperature field required for stress analysis based on heat transfer analysis. Boundary conditions are applied only to prevent rigid body motion and allow for free expansion. A snapshot of the model appears in Figure 2 that shows the mesh.

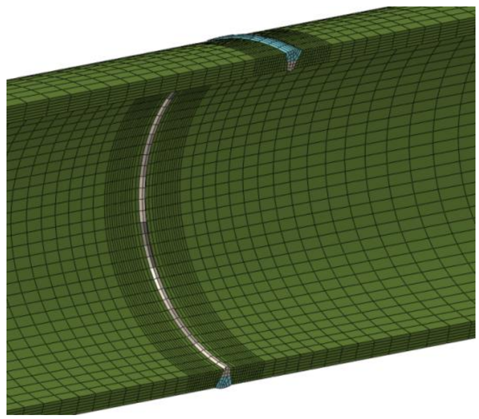

Figure 2. Half-pipe cut section showing mesh

The validation of the FEA model under study by comparison of model predictions of temperatures and residual stresses with experimental data is discussed in [4]

Figure 3 shows residual stress plot for welded pipe joint at the end of welding process.

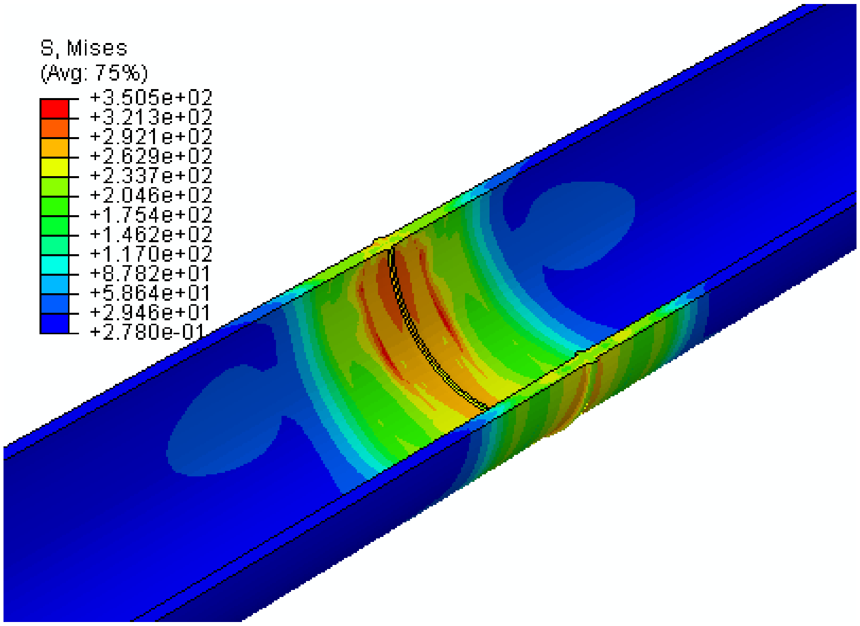

Figure 3. Residual stress distribution in MPa

3. DOE using Isight-AWI integration

The residual stresses have a complex dependency on many welding process variables, however weld sequence is one of the easiest-to-control parameters. Predicting optimal weld sequencing helps reduce the residual stresses.

The two pipes to be welded are assumed to be held together by three tack-welds at three equidistant points along circumference prior to welding. Each weld sub-pass starts from one tack-weld and ends at the adjacent tack weld. They are parameterized as ‘a’, ‘b’, ‘c’ and ‘p’, ‘q’, ‘r’ respectively for bottom and top layers as shown in Figure 4. Each sub-pass can be completed either clockwise or counterclockwise denoted by ‘+’ or ‘-‘sign respectively [1].

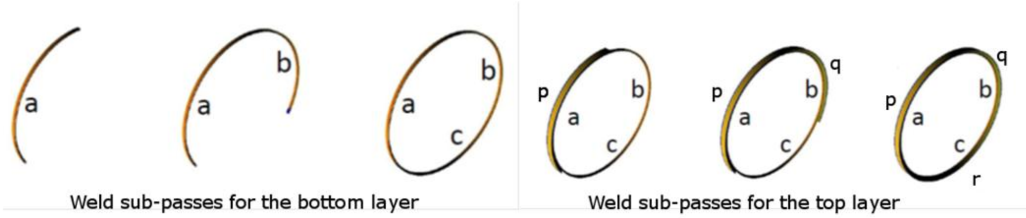

Figure 4. Welding Layers and sub-passes

3.1 DOE Strategy

DOE technique is used to identify a sequence of these 6 weld sub-passes that would produce minimum residual stress. In all there are 384 unique combinations possible for this problem. A two-step approach is employed to explore the full design space that resulted in significant savings in execution time.

In the first step, initial DOE study is performed to identify the best combination of the three sub-passes corresponding to the inner layer. 8 unique combinations are selected out of 64 possible combinations based on rotational symmetry and independence of stresses on sub-pass starting point. The best sequence is identified and frozen before proceeding to the next step.

In the second step for final DOE, in addition to the 8 combinations similar to first layer, we need to consider, 3 different positions of starting points along with clockwise and anti-clockwise directions resulting in 48 unique combinations.

Thus, a total number of 56 combinations are executed to explore the full design space.

3.2 Isight AWI Integration

The Abaqus component in Isight allows user to exchange data with Abaqus and to control the execution of Abaqus analyses. The component scans either a model database (`.cae`) file or an input (`.inp`) file and generates a list of input parameters that can be modified by Isight. The input parameters can include loads, boundary conditions, and material and section properties as well as sketcher parameters. The component launches an Abaqus analysis and reads a set of output parameters from the resulting output database (`.odb`) files or data (`.dat`) file. This solution component cannot directly operate on the parameters from AWI plug-in. This is achieved through execution of a user supplied python module called `userscript_cae_pre.py [5].`

The script performs following tasks during Isight execution:

- Importing AWI plug-in library
- Grouping of chunk elements as per weld sub-passes as described in section 2.
- Assignment of chunk elements to weld passes based on parameter value
- Building the heat transfer and stress analysis models in Abaqus/CAE

- Applying boundary conditions for stress analysis model to prevent rigid body motion
- Generation of required Abaqus input files used for heat transfer and stress analyses

3.3 Isight Workflow

The Isight workflow consists of two DOE sub-flows where each DOE sub-flow corresponds to one layer of the weld joint. In the Figure 5, DOE Layer 1 is for inner layer of weld joint and DOE Layer 2 is for the outer layer. Each DOE sub-flow consists of two Abaqus solution components in sequence; with first for heat transfer analysis followed by stress analysis. For DOE Layer 1, the input parameters are weld sub-pass 1, weld sub-pass 2 and weld sub-pass 3 with allowed values '±a', '±b', '±c'. The objective of DOE sub-flow was set to minimize residual stress at the end of weld sub-pass 3. Similarly for DOE Layer 2, the input parameters are weld sub-pass 4, weld sub-pass 5 and weld sub-pass 6 with allowed values '±p', '±q', '±r' and objective to minimize residual stress at the end of weld sub-pass 6.

The user script (`userscript_cae_pre.py`) is used as input file parameter for Abaqus component Heat Layer. This component generates Abaqus input file corresponding to heat transfer analysis. The output database file of this analysis is parsed as input file parameter for the next component Stress Layer. The residual stress values are obtained from Stress Layer Abaqus component.

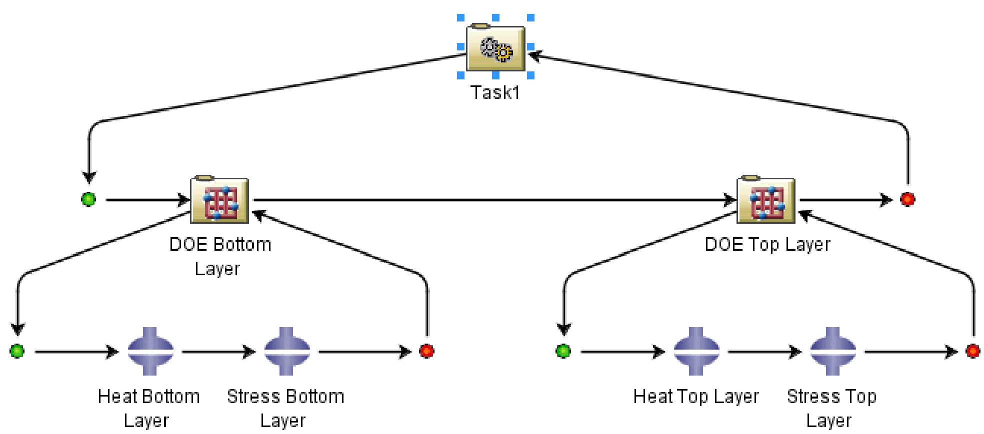

Figure 5. Isight Work-flow

3.4 DOE Results

Figure 6 shows the results of DOE Layer 1. It is observed that for the first layer of weld, minimum residual stress at the end of sub-pass 3 is 509.5 MPa. The weld sequence corresponding to this design point is [+a: +b: -c]. This sequence is identified as the best sequence and frozen for DOE Layer 2.

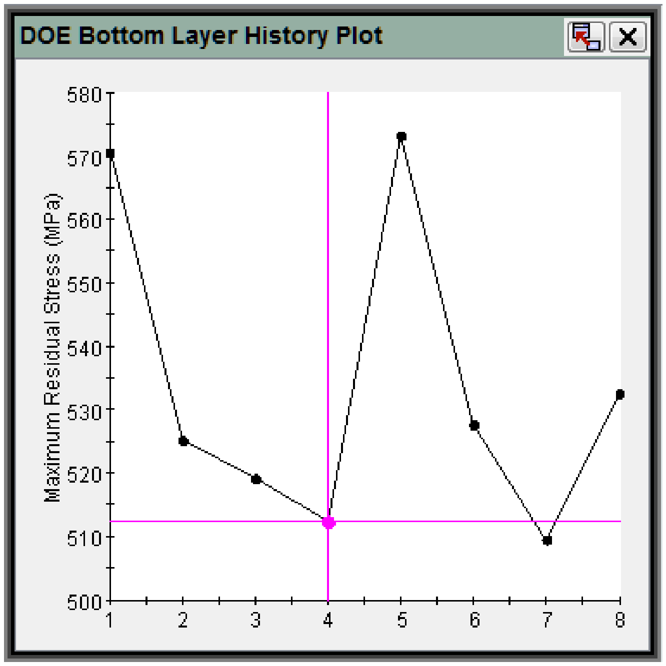

Figure 6. History Graph for Residual Stresses in DOE Bottom Layer

For DOE Layer 2, Figure 7 shows maximum residual stress value at the end of sub-pass 6 for each DOE run. It is observed that minimum residual stress value is 334.5 MPa denoting DOE run 40. The weld sequence corresponding to this point is [-r: -p: -q]. It is also observed that maximum value of residual stress is 392 MPa for weld sequence [+r: -p: +q].

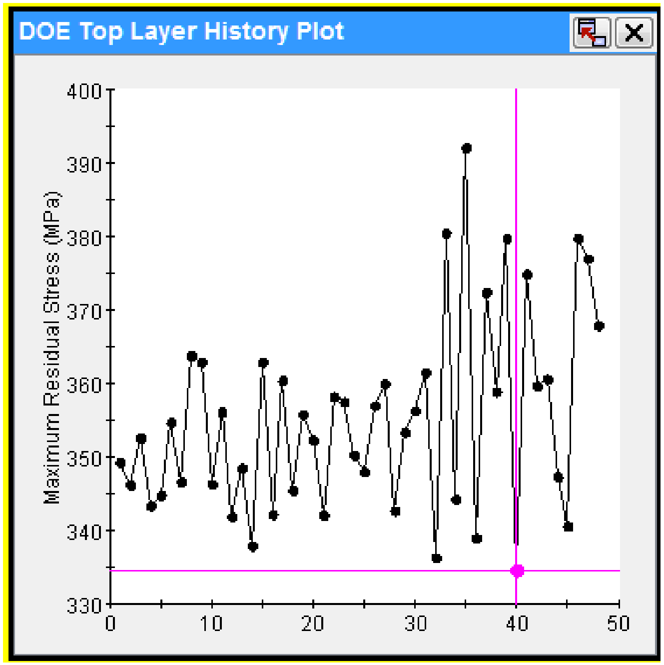

Figure 7. History Graph for Residual Stresses in DOE Top Layer

Table 1 explains the comparison of residual stresses for different combinations of weld sequence. With the DOE technique, the optimum weld sequence results in about 5 % reduction in maximum residual stress as compared to continuous sub-passes in welding layers.

Weld Sequence		Max. Residual Stress	Variation wrt Best	
Absolute Best	+a: +b: -c :: -r: -p: -q	334.5 MPa		
Continuous	+a: +b: +c :: +p: +q: +r	350.5 MPa	5%	↑
Observed Worst	+a: +b: -c :: +r: -p: +q	392 MPa	17%	↑

Table1. Comparison of Results

4. Conclusion

AWI presents itself as an attractive choice in simulating real world welding problems easily, given the significant time savings in model setup compared to manual approach.

The study demonstrates the significance of weld sequencing in reducing residual stresses and how Isight-AWI integration can be effectively used to achieve optimal sequencing. In a typical industrial context where the number of layers and sub passes would be considerably larger, this solution would greatly reduce the prototyping costs. Same study can be extended to other weld process parameters like weld speed, torch temperature, inter pass cooling time etc.

5. References

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