Development of Online Weld Modeling Tool for Automotive Applications

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General Motors LLC
Outline

• Introduction of online weld modeling tool (EWI WeldPredictor)
• Customization of WeldPredictor for automotive applications
• Summary and future development
• Acknowledgement
Development of Online Weld Modeling Tool

- Weld modeling technology has been developed for many years and demonstrated successfully in solving industrial problems.
- To help Industries access the weld modeling technology, an online modeling tool (EWI Weld Predictor) was developed by combining the power of numerical weld modeling and high performance computational hardware.
- Significant effort and funding were investigated during the development:
  - EWI project team members including S. Babu, S. Khurana, W. Zhang, W. Gan, J. Xu, H. Kim, and Y. Yang
  - OSC project team members including N. Ludban and L. Yang
EWI WeldPredictor

- Secure website
- Easy access to advanced weld modeling tools
- Arc welding procedures
- Single and multi-pass welding simulation
- Predict
  - Temperature
  - Hardness
  - Residual stress
  - Distortion

https://eweldpredictor.ewi.org/
Structure of WeldPredictor

End Users

Graphic User Interface (Authenticated Secure Website)

- Geometry
- Welding parameters
- Materials
- Reports

Front End

ABAQUS/CAE

Mesh

User subroutines for welding simulation

ABAQUS/STANDARD

Back End

ABAQUS/VIEWER

Results
Simulating Pipe and Plate Welding
User Defined Weld Bead Shape and Position

Bead shape:
• Parabolic
• Ellipse
• Complex

Bead size can be adjusted.
Standard Industrial Groove Design: Butt and Tee Joint
Built-in Material Database

Dissimilar material joining can be simulated by selecting different materials for Part 1 and Part 2.

Filler wire is recommended by WeldPredictor or selected by users.
Simulate Weld Fixture and Monitoring Temperature History

- Allows users to define fixed locations and cooling surfaces (copper block and water)
- Allows users to define temperature monitoring locations such as thermocouple locations
Automatically Mesh Generation

**Automatic meshing**

- Complex bead shape
- User-defined bead sequencing
- Fast
Butt-Joint Analysis Results: Temperature Prediction

Multi-pass welding simulation
- Predict temperature distribution for given welding parameters
- Predict weld microstructure by inputting predicted temperature history
- Assist weld process development
T-Joint Analysis Results: Temperature and Hardness

**Single and multi-pass T-fillet simulation**

- Optimize welding sequence by alternating weld passes to control distortion
- Control hardness in the weld range by varying heat inputs

Distributions of reheating temperature (°C)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1545.00</td>
<td>red</td>
</tr>
<tr>
<td>1327.86</td>
<td>yellow</td>
</tr>
<tr>
<td>1110.73</td>
<td>green</td>
</tr>
<tr>
<td>892.57</td>
<td>blue</td>
</tr>
<tr>
<td>676.43</td>
<td>dark blue</td>
</tr>
<tr>
<td>459.29</td>
<td>light blue</td>
</tr>
<tr>
<td>242.14</td>
<td>cyan</td>
</tr>
<tr>
<td>25.00</td>
<td>white</td>
</tr>
</tbody>
</table>

Distribution of Vickers Hardness

<table>
<thead>
<tr>
<th>Hardness</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>269.32</td>
<td>red</td>
</tr>
<tr>
<td>256.80</td>
<td>yellow</td>
</tr>
<tr>
<td>246.25</td>
<td>green</td>
</tr>
<tr>
<td>235.22</td>
<td>blue</td>
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<tr>
<td>224.01</td>
<td>dark blue</td>
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<tr>
<td>216.74</td>
<td>light blue</td>
</tr>
<tr>
<td>209.48</td>
<td>cyan</td>
</tr>
</tbody>
</table>

Model Validation: Single Bead

Temperature measurement with thermocouples

Hardness distribution

Weld cross section

Temperature

Hardness
To validate the online modeling tool, multi-pass welding was conducted and temperature data was collected.
WeldPredictor is able to predict fusion-zone profile with a reasonable accuracy.
Customize WeldPredictor for Automotive Applications

- Automotive industry shows interests in applying WeldPredictor for welding procedure development
- Special requirements from automotive industry
  - Simulate lap-joint welding
  - Predict weld size
  - Input material coating
  - Input detailed welding procedures
- To meet these requirement, WeldPredictor was customized by:
  - Improve backend to predict weld sizes
  - Conduct experimental trial for model validations
  - Design a new interface
Backend Improvement: Development of A Weld-Bead Predictor

- A weld-bead predictor was developed to predict weld size by inputting plate dimensions, welding parameters, and materials properties.
- The weld-bead predictor includes:
  - A thermal model
  - A analytical equation
  - A weld-bead display webpage
Backend Improvement: Considering Torch Angle

- The heat source model for thermal analysis is a Goldak’s double ellipsoidal model

\[ q(t) = f \frac{6\sqrt{3}Q\eta}{abc\pi\sqrt{\pi}} e^{-\frac{3x^2}{a^2}} e^{-\frac{3y^2}{b^2}} e^{-\frac{3[z_0+vt]^2}{c^2}} \]

- \(a\), \(b\), and \(c\) are the semi-axes of the ellipsoid
- \(\eta\) is heat efficiency and \(f\) is a heating factor
- \(Q\) is the power of arc welding process
- \(v\) is the traveling speed
- \(z_0\) is a distance constant and \(t\) is the time

- Assuming torch angle \(\theta\), \(x\) and \(y\) can be calculated with the coordinate transformation equations as follows:
  - \(x = X\cos(\theta) - Y\sin(\theta)\)
  - \(y = X\sin(\theta) + Y\cos(\theta)\)
Experimental Trials

• Lap joint experimental trials were conducted to measure weld shape size to validate the prediction of the weld bead predictor

• Experiment was conducted in six materials
  – 1: 1.2mm Mild
  – 2: 1.0mm DP780
  – 3: 1.0mm M190
  – 4: 1.14mm HSLA
  – 5: 1.2mm DP600
Experimental Trials: Macrographs of Weld Cross Sections

Bead size was compared with model predictions.
A lap-joint interface was designed to allow a user to input part dimensions.

For this demonstration version, the plate length and overlapping distance are fixed.

Thickness can be changed from 0.7 to 1.5mm.
Interface Design: Material Inputs

Material coatings

www.autosteel.org
Interface Design: Procedure Inputs

Welding Parameters

<table>
<thead>
<tr>
<th>Pass</th>
<th>Wire Feed Speed (IPM)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
<th>Travel Speed (IPM)</th>
<th>Heat Input (J/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>107.0</td>
<td>100-341</td>
<td>66.0</td>
<td>17.0</td>
<td>20.0</td>
<td>3366</td>
</tr>
</tbody>
</table>

Welding Conditions

- Filler wire size (inch): 0.035
- Shielding Gas: 80% Ar + 10% CO2
- Shielding Gas Flow Rate: 35 CFH
- Welding Position: V
- Welding Equipment Type and Model: OTC DP-460
- Transfer Mode: Short Circuit
- Electrode Polarity: DCBP
- Torch Angle: 30 Degree
- Contact Tip to Work Distance: 10
- Stringer (Y) or Multiple (H) Bead: 5
- Forehand (F) or Backhand (B): F

Limitations:
- Wire feed speed: 100-341 IPM
- Current: 61-135 A
- Voltage: 16-20 V
- Travel speed: 17-28 IPM

Cannot be changed for this version

Instructions

Please provide the approximate welding process parameters including wire feed speed, voltage, current, and travel speed. Make sure that the process parameters (heat input values) are close to the practical conditions. Unrealistic process parameters may lead to two possible scenarios:

1. too-low heat input: insufficient melting
2. too-high heat input: excessive melting
Interface Design: Weld-Size Prediction

Comparison (DP600)

Measurement

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>a</td>
<td>1.5</td>
</tr>
<tr>
<td>b</td>
<td>3.0</td>
</tr>
<tr>
<td>c</td>
<td>1.9</td>
</tr>
<tr>
<td>d</td>
<td>1.1</td>
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</tbody>
</table>

Welding parameters:

<table>
<thead>
<tr>
<th>Pass</th>
<th>Wire Feed Speed (IPM)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
<th>Travel Speed (IPM)</th>
<th>Heat Input (J/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120.000</td>
<td>66.000</td>
<td>17.000</td>
<td>20.000</td>
<td>3366.000</td>
</tr>
</tbody>
</table>

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Effect of Heat Input on Weld Size for Mild Steel

(a) Heat Input (3417J/in)

With heat input increases, the size of fusion zone (>1500°C) increases.

(b) Heat Input (4156J/in)

This tool was used to determine the right heat input:
- 3417J/in is too low
- 4156J/in is fine
- 5378J/in is slight high

(c) Heat Input (5378J/in)
Effect of Heat Input on Weld Size for DP600

- With heat input increases, the size of fusion zone (>1500°C) increases.
- This tool was used to determine the right heat input:
  - 3417J/in is fine
  - 5378J/in is too high
Predicted Hardness, Residual Stress, and Distortion

Vickers Hardness

| Hardness | 354.07 | 334.48 | 314.86 | 295.28 | 275.69 | 256.09 | 236.49 | 216.90 |

Von Mises Stress

Unit: MPa

| S. Mises (Avg: 75%) | 607.83 | 540.29 | 472.75 | 405.22 | 337.68 | 270.15 | 202.61 | 135.07 | 67.54 | 0.00 |

Y-Displacement

Unit: mm

<table>
<thead>
<tr>
<th>Y-Displacement</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse displacement (mm) *</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Angular distortion (degree) **</td>
<td>0.36</td>
<td>0.43</td>
</tr>
</tbody>
</table>

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Summary and Future Development

• An online weld modeling tool (WeldPredictor) was developed
  – Easy-to-use online tool simulating arc welding
  – Prediction of weld size, microstructure, thermal profiles, residual stresses, and distortion
  – Quickly exploring a wide range of “what-if” scenarios
• The online tool was customized for automotive lap joint simulation for demonstration purpose
• Further development is needed to improve the prediction accuracy for automotive applications
• User defined geometry is under development. This feature will allow a user to define an exact part geometry.
Acknowledgement

• The customized WeldPredictor for automotive application was supported from the Department of Energy National Energy Technology Laboratory under Award No. DE-FC26-02OR22910.
• Auto/Steel Partnership project manager, M. S. Bzdok, and joining team provided much advice during development.
• AET Integration, Inc. provided help for welding the specimens.
• ArcelorMittal Dofasco helped to collect material data.
• EWI acknowledges the financial support from Ohio Department of Development to develop EWI WeldPredictor.
• The authors are grateful to W. Gan, S.P. Khurana, S.S. Babu, and C. Conrardy for their contributions in WeldPredictor development.
• The authors also sincerely thank the Ohio Supercomputer Center for implementing of the front-end and hosting the EWI WeldPredictor.