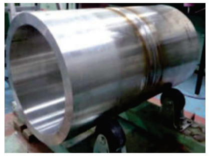
Large-scale Numerical Analysis of Multi-Pass Welding Using Automesh and Idealized Explicit FEM

Osaka Metropolitan University

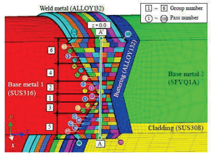
○ Wenda WANG, Shintaro MAEDA, Kazuki IKUSHIMA, Masakazu SHIBAHARA

Introduction



Ring specimen for welding

Actual welded cross-section



Mesh distribution in welding simulation

Problem(Challenges in Multi-layer Welding Simulation)

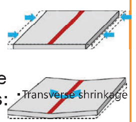
Human effort in modeling

- **Number of design parameters:** Large
- **Deformation must be considered in design**
- **Design difficulty:** High

Iterative simulations

Target Deformation

- **Number of weld passes:** Large
- **Welding distortion:** Large
- **Distortion vs. conditions:** Nonlinear



This study: To establish a **fast and automated** welding simulation by integrating **IEFEM and Automesh system**

➡ Enable efficient prediction of residual stress and deformation in large and complex welded structures

Numerical methodology: IEFEM and Automesh

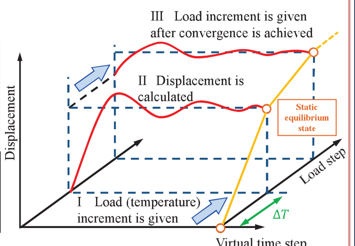
Concept of IEFEM

IEFEM

- **Uniform time-step size** across mesh, regardless of element size/material
- **Critical damping** per DOF → suppresses oscillations
- **GPU-parallel friendly** → element-local updates scale

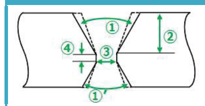
Dynamic explicit FEM

- Requires very small stable time steps
- Long run-time to reach quasi-static equilibrium
- Numerical oscillations unless strong damping working

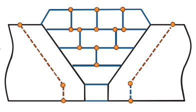


Smaller memory and faster computation

Framework of Automesh



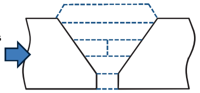
- Groove angle
- Bevel depth (X-groove)
- Root gap width
- Root gap height
- Reinforce heigh
- ……

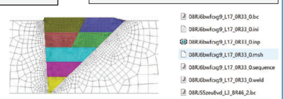


Model and simulation setup generated in only 10–20 s

Parameter Input and Validation → Geometric Parameterization and Segmentation → Point Clouds and HAZ Modeling → 3D Extension and Meshing/Mesh Quality and Export /Analysis file Generation

- Number of passes
- Layer thickness
- Pass aspect ratio
- ……

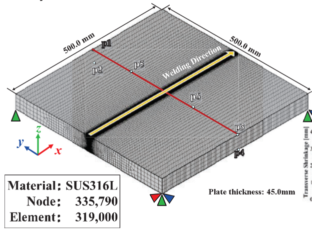




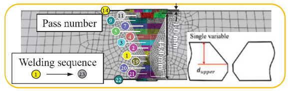
Automesh delivers fully automated model building and analysis setup for welding simulations

Analysis of X-groove geometry

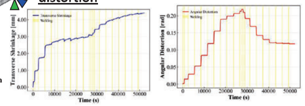
Analysis model



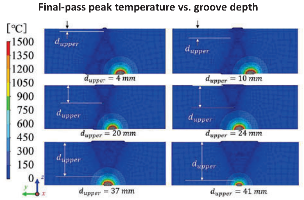
Multi-pass weld cross-section



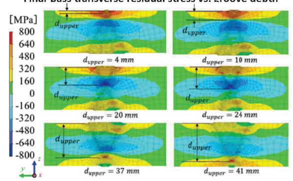
Deformation history (all pass): shrinkage and distortion

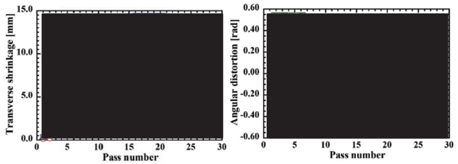


Final-pass peak temperature vs. groove depth



Final-pass transverse residual stress vs. groove depth

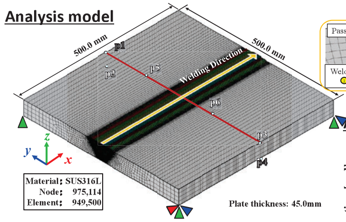




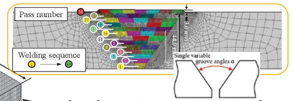
- **Enables rapid, detailed analysis**
- **Near-symmetric X-groove depth (~24 mm, half plate thickness) produced the smallest shrinkage and distortion.**

Analysis of V-groove geometry

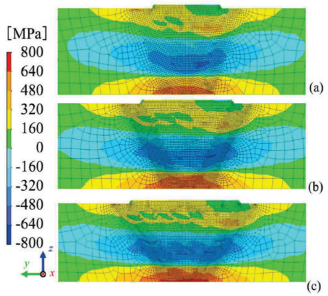
Analysis model



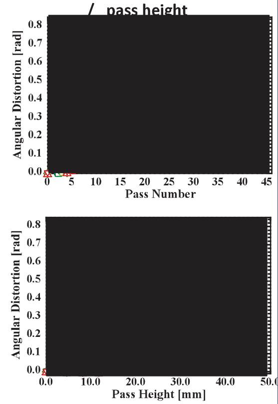
Multi-pass weld cross-section



Residual stress (final pass) for V-groove joints with groove angles 40°, 55°, 70°



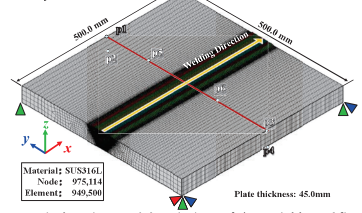
Angular distortion vs. pass number / pass height



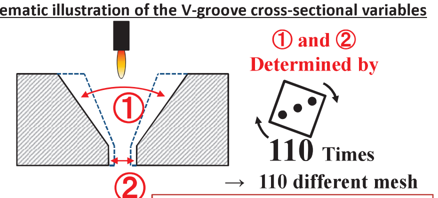
Isolate single effects (groove angle) by quantitatively controlling all other parameters

Groove Angle & Root Gap: Multivariate Study

Analysis model



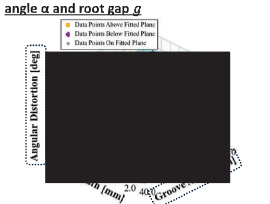
Schematic illustration of the V-groove cross-sectional variables



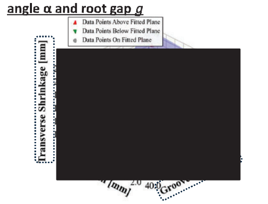
Numerical settings and descriptions of the variable and fixed parameters adopted for the multivariate analysis

Category	Parameter	Value / Range	Description
Variable Parameters	①Groove angle	40.0° –70.0°	Randomly sampled within this range
	②Root gap width	1.0 mm – 10.0 mm	Randomly sampled within this range
Fixed Parameters	Root gap height	1.0 mm	Constant across all configurations
	Layer thickness	First: 4.67 mmIntermediate: 3.67 mmFinal: 3.00 mm	Fixed by layer type
	Number of passes	Closest to aspect ratio 1:3	Determined to approximate aspect ratio
	Heat input	50.0 J/mm³ (proportional to cross-sectional area)	Uniform per pass
	Welding speed	3.0 mm/s (all passes)	Constant across all passes

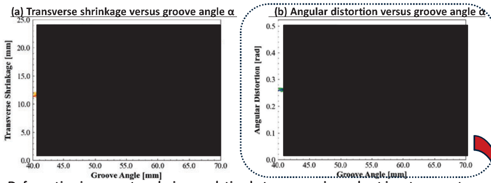
Transverse shrinkage plotted against groove angle α and root gap g



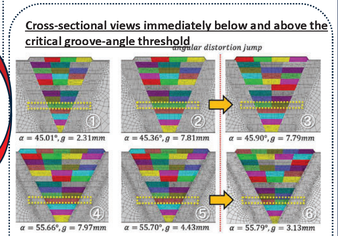
Angular distortion plotted against groove angle α and root gap g



Influence of groove angle on deformation responses in V-groove multi-pass welding

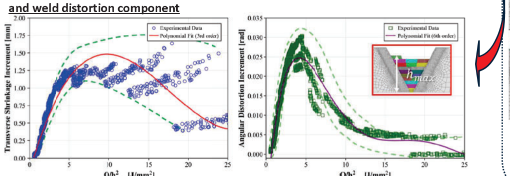


Cross-sectional views immediately below and above the critical groove-angle threshold

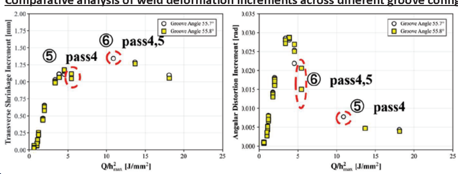


showing how a discrete change in the number of passes within the dominant height band (shaded) amplifies the resulting angular distortion

Deformation increment analysis: correlation between maximum heat input parameter and weld distortion component



Comparative analysis of weld deformation increments across different groove configurations



Automesh reveals that even small geometric perturbations can cause significant deviations, and splitting large heat-input regions into more passes amplifies angular distortion

Conclusions

By combining Automesh with GPU-accelerated IEFEM, this study achieved high-fidelity thermo-elastic–plastic analysis of ultra-large multi-pass welds. The workflow eliminates meshing bias, reveals discrete geometric effects, and enables practical large-scale parametric exploration that would be infeasible with conventional implicit solvers.