Study of Solidification Cracking under FCB Welding of Butt Welding.

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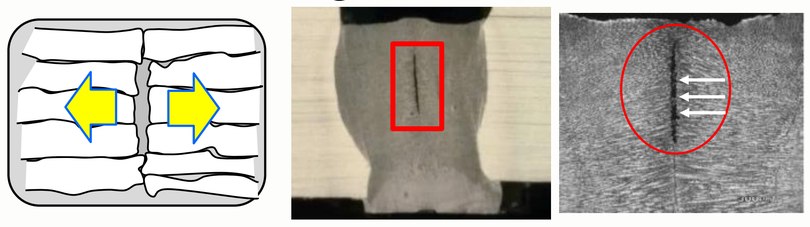
Background

Solidification cracking



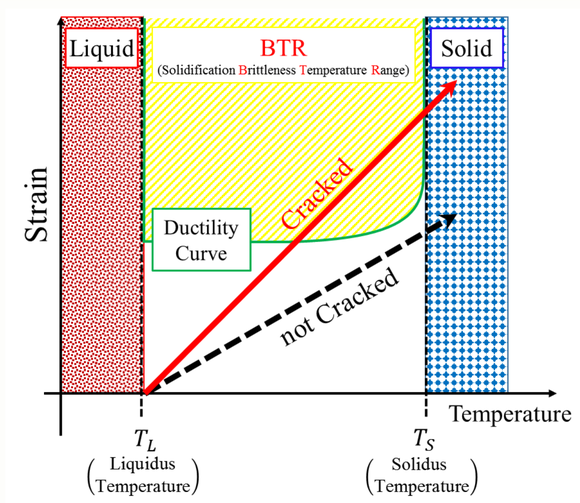
Hot cracking may decrease the strength of the structure.
Repair welding necessary if it is occurred.

- Increase of production cost
- Decrease of production efficiency

Objective of this study

- Prediction of occurrence of hot crack in analysis
- Consider hot crack prevention measures on analysis

Concept of occurrence of hot crack



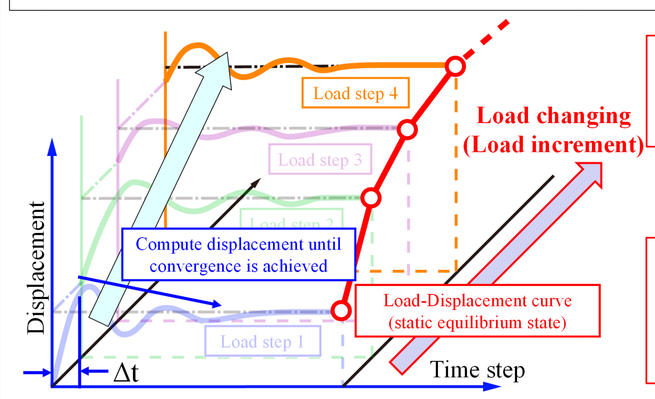
Evaluation of strain on weld metal during BTR by FEM analysis.

Idealized Explicit FEM

Concept of IEFEM

IEFEM

In a load step, displacement is calculated using Dynamic Explicit FEM until the entire domain converges to **static equilibrium state**.



After convergence is obtained, the next load increment is given.

By using these procedures, it is not necessary to solve the large simultaneous equations.

Smaller memory and **Faster computation**

BTR plastic strain increment

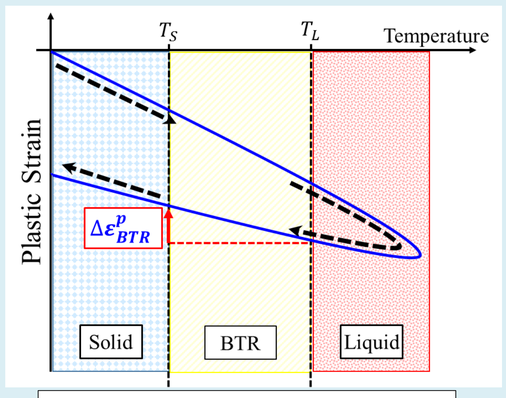
Strain in FEM

$\{\Delta\varepsilon\} = \{\Delta\varepsilon^e\} + \{\Delta\varepsilon^p\} + \{\Delta\varepsilon^T\}$

$\Delta\varepsilon^e$: Negligibly small because of high temperature

$\Delta\varepsilon^T$: Negative value proportional to BTR in cooling process.

$\Delta\varepsilon^e$ and $\Delta\varepsilon^T$ are not considered to themselves cause cracking in cooling process.

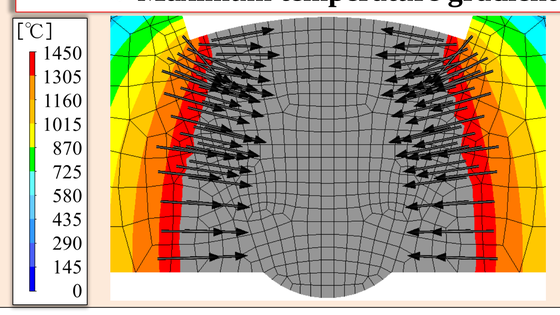


BTR plastic strain increment:
Plastic strain increment $\Delta\varepsilon^p$ in the BTR during cooling

BTR plastic strain increment $\Delta\varepsilon^p_{BTR}$ is used as an generation index of hot cracking

Prediction of crystal growth direction and hot crack occurrence position

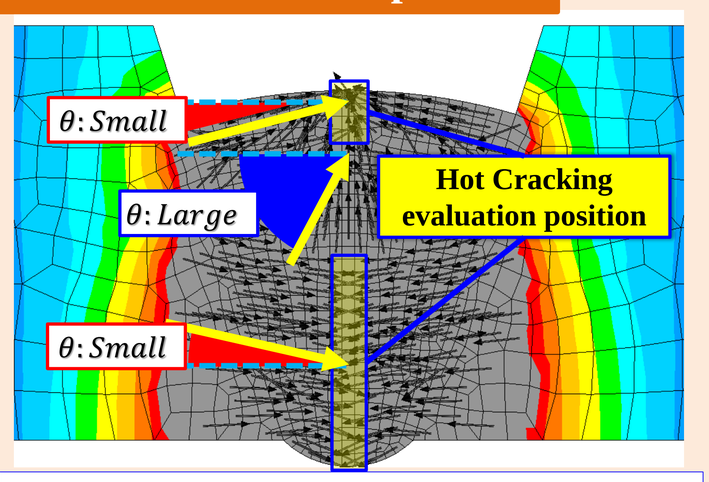
Crystal growth direction ≒ Maximum temperature gradient



BTR Temperature Gradient Vector :
Temperature gradient in the BTR during cooling

BTR Temperature gradient vector :

$$\nabla T_{BTR} = x_i \frac{\partial T}{\partial x} + y_j \frac{\partial T}{\partial y} + z_k \frac{\partial T}{\partial z}$$



Columnar Association Angle θ

θ : *Small* → *Hot Crack Resistance* : *Small*

θ : *Large* → *Hot Crack Resistance* : *Large*

Prediction of solidification cracking position from ∇T_{BTR} on association part

Applied to 4-electrodes One-side submerged arc welding

Analysis model

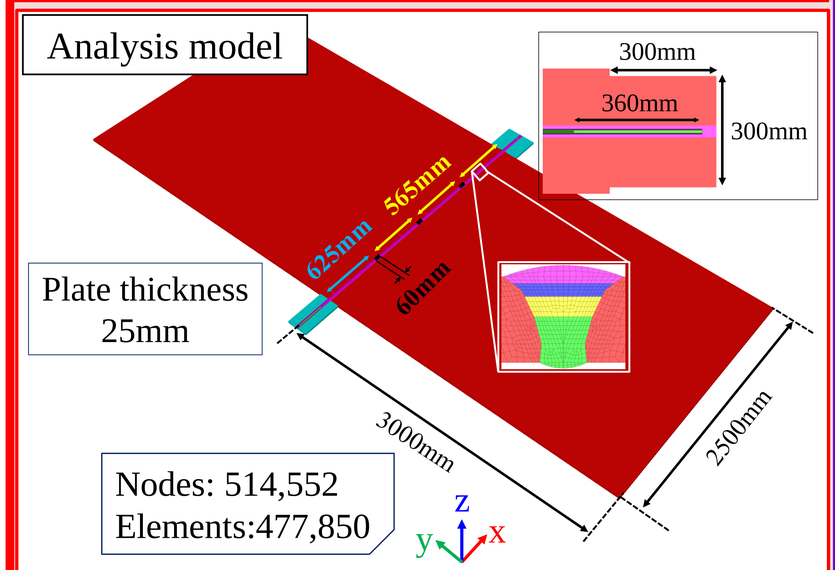
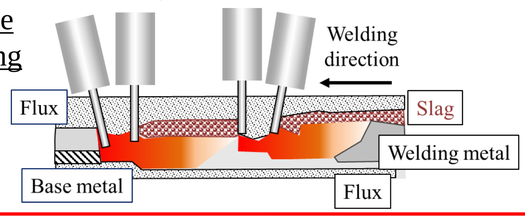


Plate thickness 25mm

Nodes: 514,552
Elements:477,850

4-electrodes One-side submerged arc welding



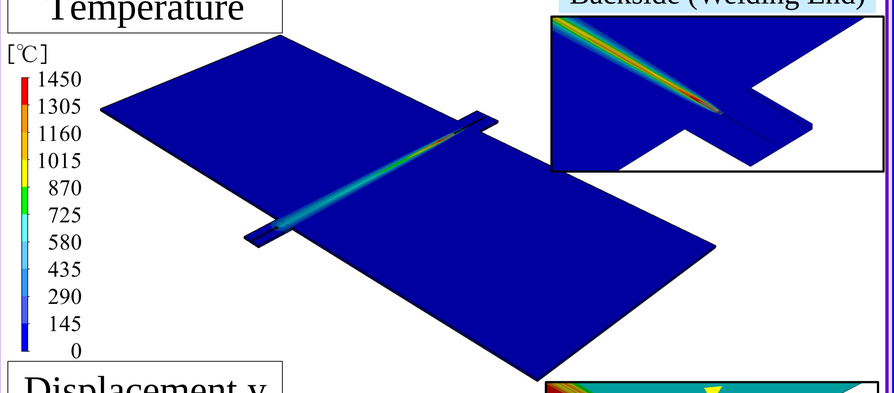
Total heat input

12.1 kJ/mm

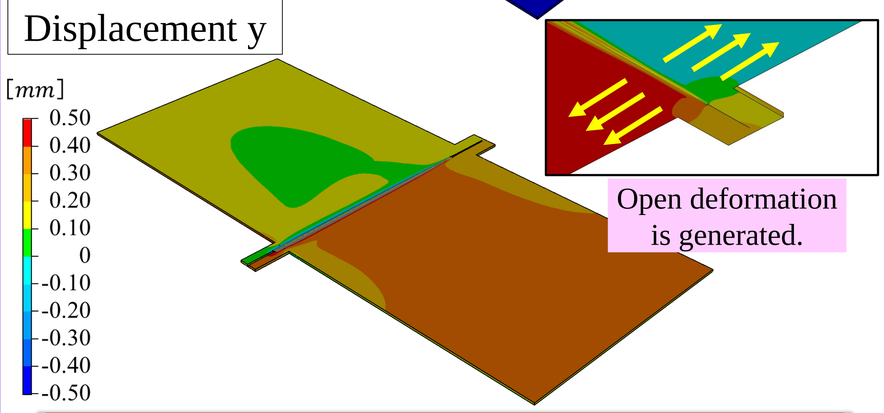
Thermal elastic plastic analysis results

Temperature distribution Backside (Welding End)

Temperature

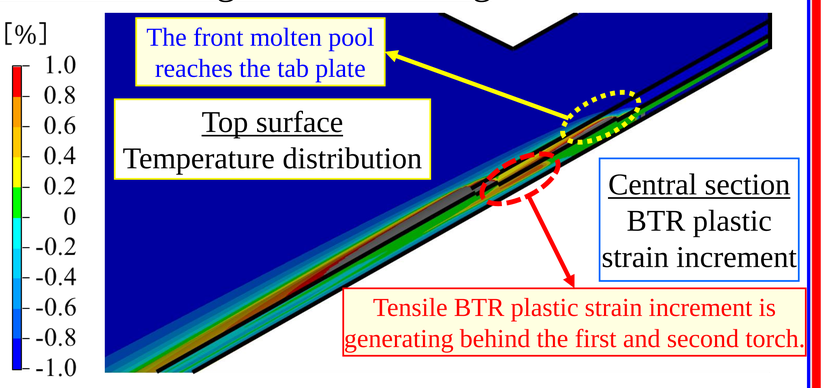


Displacement y

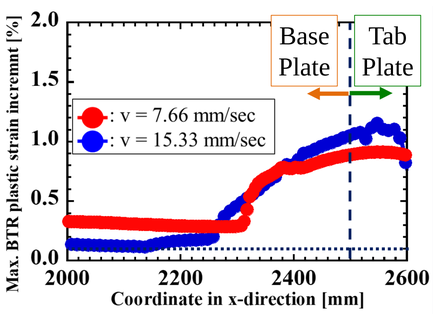


Sequential analysis with moving heat source is performed.

Tensile strain generation timing

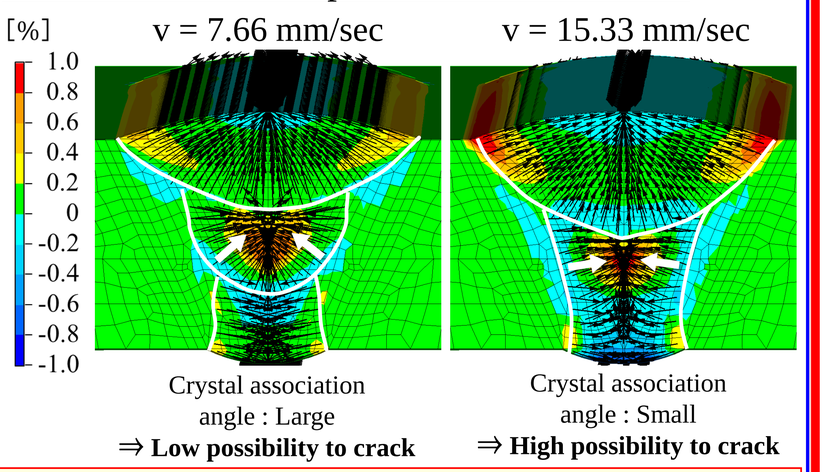


Distribution of BTR plastic strain increment



- BTR plastic strain increment becomes larger at weld end
- Smaller welding speed generate smaller BTR plastic strain increment

Distribution of BTR plastic strain increment

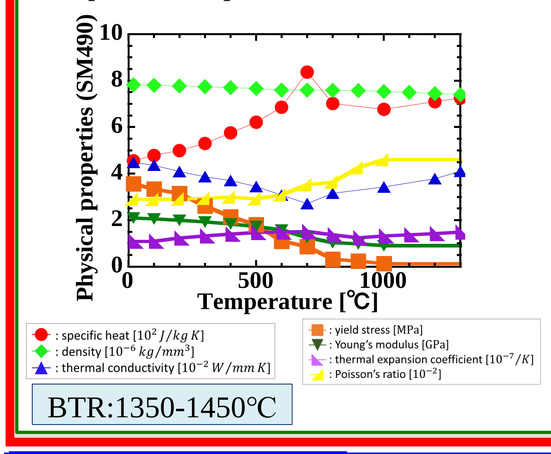


Crystal association angle : Large
⇒ **Low possibility to crack**

Crystal association angle : Small
⇒ **High possibility to crack**

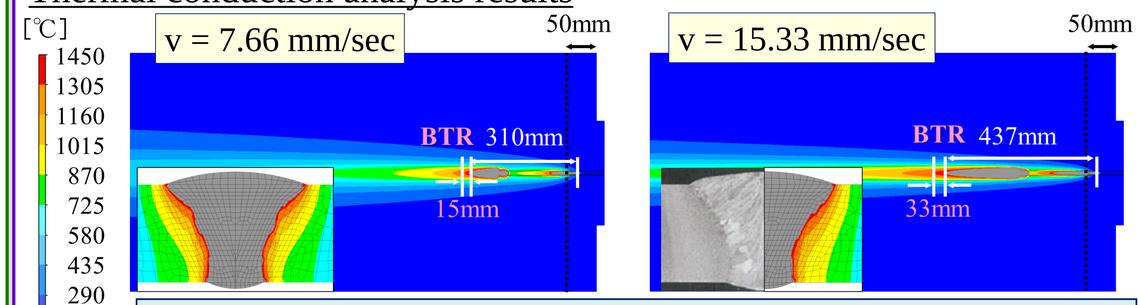
Small welding speeds may reduce hot cracking.

Temperature dependent material constants



BTR:1350-1450℃

Thermal conduction analysis results



- The larger the welding speed, the longer the BTR length.
- Penetration shape of analysis result is in good agreement with experimental results.

Conclusion

In this research, a new crack generation evaluation method based on mechanics and metallurgy has been proposed. From the metallurgical viewpoint, the solidification growth direction is predicted by using the BTR temperature gradient vector. And the hot cracking resistance is evaluated from columnar association angle. From the mechanical side, strain generated in the molten and solidified part is evaluated using the BTR plastic strain increment. Then, the proposed method was applied to 4-electrode One-side submerged arc welding. The following results were obtained:

- It was confirmed that the penetration shape and crystal association angle changes with the welding speed.
- In the small welding speed condition, BTR plastic strain increment become small and the crystal association angle become large.
- This indicates that changing the welding speed may be effective to prevent solidification cracking.