Numerical modelling of thermal-mechanical evolution during high heat input welding of marine steel

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Introduction: The high heat input welding improves the efficiency, but the toughness of heat-affected zone (HAZ) can be reduced significantly because of thermal-mechanical evolution in HAZ during welding.

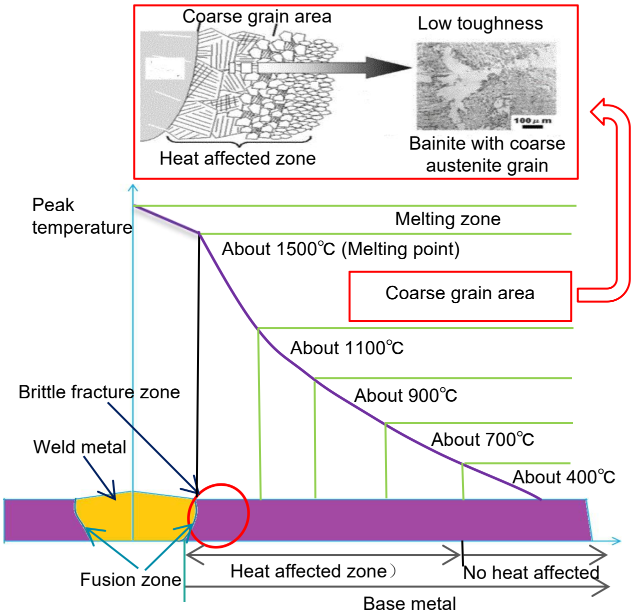


Figure 1. Thermal distribution and phase evolution during the welding

Methodology: A coupled heat transfer, solid mechanics and phase transformation model has been developed to simulate the high heat input electro-gas welding (EGW) process of marine steel.

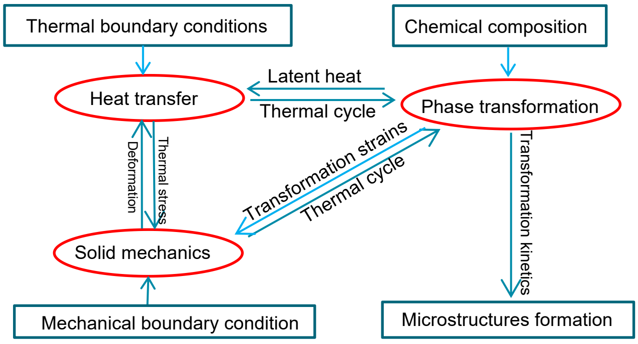


Figure 2. The coupling between thermal, stress and phase evoluation

Temperature field:

Thermal balance equation $$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = Q$$

ρ - Density C_p - Heat capacity k - Thermal conductivity

Heat source $$Q = \frac{3P}{\pi r_H^2} \exp\left[-3 \frac{\left(y - \frac{d}{4} \sin \frac{2\pi t}{T}\right)^2 + (z - vt)^2}{r_H^2}\right]$$

P - Arc power r_H - Radius of heating source v - Welding speed

Phase field:

Ferrite transformation rate is computed by LD-equation

$$A_{s \to d} = K_{s \to d} \xi^s - L_{s \to d} \xi^d$$

ξ^s - Ratio of consumption phase ξ^d - The ratio of target phase

Bainite volum fraction is computed by JMAK-equation

$$f_b = K \cdot n \cdot t^{n-1} \cdot \exp(-K \cdot t^n)$$

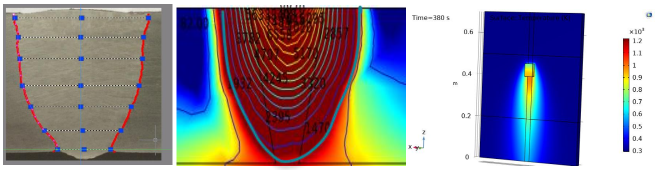
K - Constant t - Transformation time

Martensite volum fraction is computed by KM-equation

$$f_m = 1 - \exp(-0.011(M_s - T))$$

Ms - Martensite start temperature *T* - Temperature

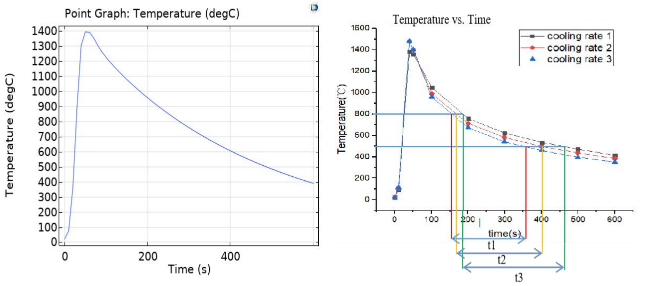
Result: The simulated thermal profile is validated by comparing experimental and simulated fusion lines in welding joints (Figure 3).



(a) Real welded joint (b) Simulated welded joint (c) Simulated cloud picture

Figure 3. Comparison of actual and simulated welded joints

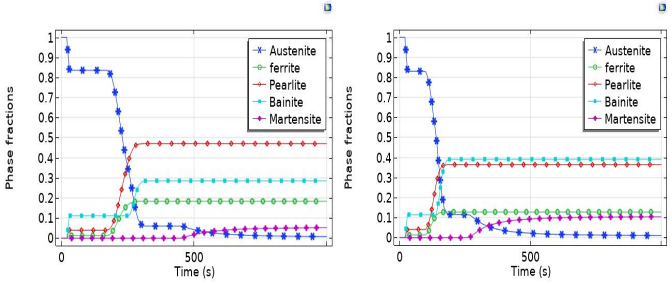
Temperature evolution against time for a selected point is shown in Figure 4. The effect of cooling rate of water-cooled copper slides on temperature evolution can be analysed and are shown in Figure 4(b).



(a) Thermal cycle of selected point (b) Thermal cycle with three cooling rates

Figure 4 Thermal evoluation during welding process

Calculated phase fraction of HAZ evolution with different thermal cycle are shown in Figure 5. With the increase of cooling rate, the fraction of bainite and martensite increases while the fraction of pearlite and ferrite decreases.



(a) Cooling rate 1 (b) Cooling rate 3

Figure 5. Phase fraction smulation of HAZ with different cooling rate

Conclusion: A coupled heat transfer, solid mechanics and phase transformation model has been developed to simulate the high heat input welding of marine steel. Simulated thermal results have been validated against experimental observations. It is found that microstructure evolution during welding can be optimized by varying the welding source movement path and the cooling rate of sliding copper shoe to improve the properties of HAZ.

References

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