Numerical Analysis of Effect of Surface Active Elements on Marangoni Flow in Melt Pool

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Introduction: Numerical simulation is used to show the dependence of flow field and resulting melt pool shape on the surface active elements. Stainless steel alloy has been used as base for the modeling and sulfur is studied as the surface active element.

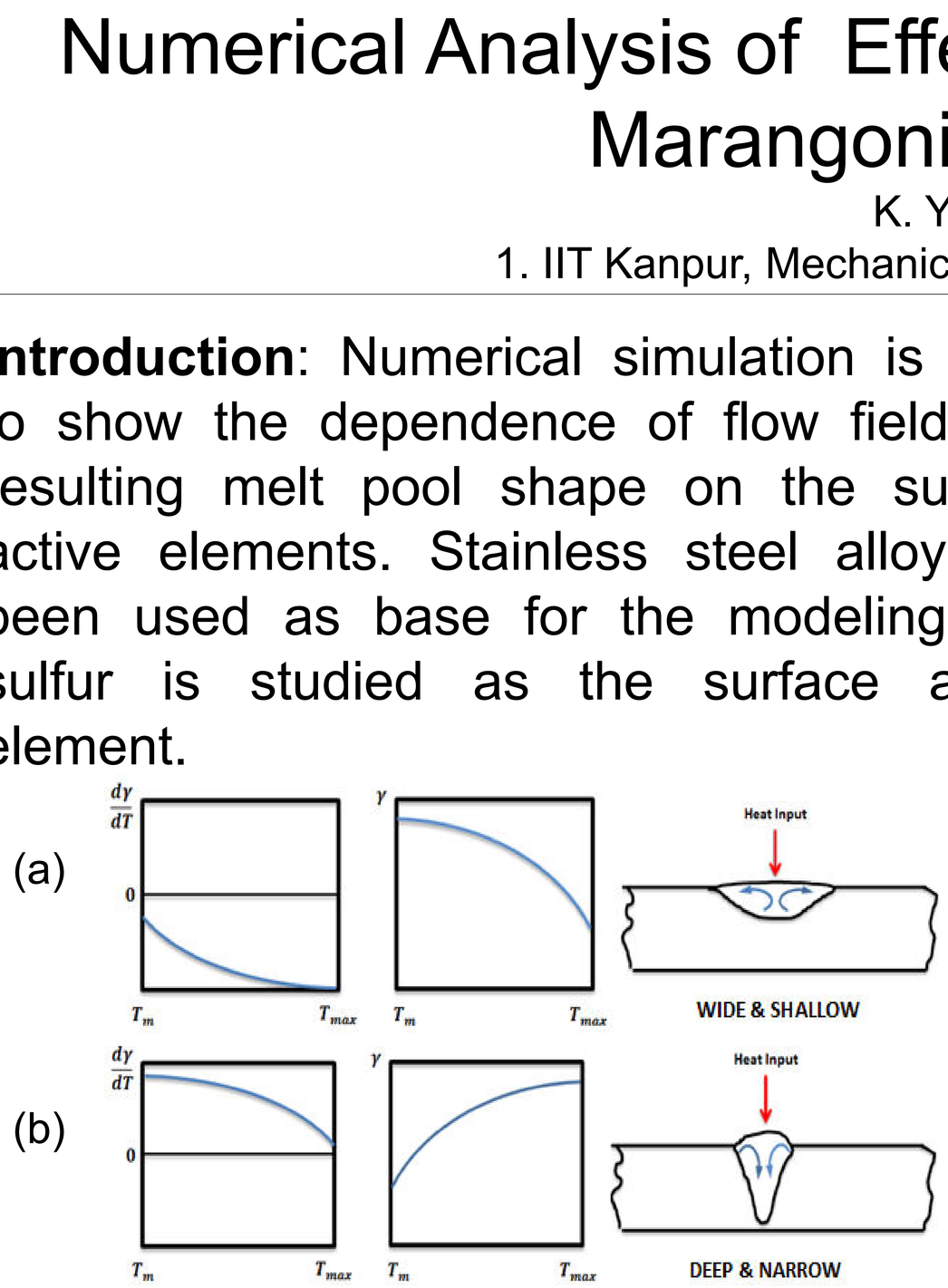

Figure 1. Wide and shallow pool by negative gradient(top) and Deep and narrow pool by the positive surface tension gradient(bottom).

Computational Methods: 2-D numerical modeling of Marangoni convection has been done for the laser spot welding of stainless steel to study the flow pattern changes. The variations in the surface tension gradient due to changing concentration of sulfur are taken into account.

Continuity Eq.

$$\frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} = 0$$

Heat source (laser beam) with Gaussian distribution

$$q_{in} = \frac{2P}{\pi r^2} \exp\left(-\frac{2x^2}{r^2}\right)$$

Momentum equation(x-direction):

$$-\frac{\partial(\rho u_x v)}{\partial x} + \frac{\partial \rho u u}{\partial x} + \frac{\partial \rho v u}{\partial y} = -\frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left(\frac{\mu \partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\mu \partial u}{\partial y}\right) + Sx$$

Momentum equation(y-direction):

$$-\frac{\partial(\rho u_x v)}{\partial x} + \frac{\partial \rho u v}{\partial x} + \frac{\partial \rho v v}{\partial y} = -\frac{\partial P}{\partial y} + \frac{\partial}{\partial x}\left(\frac{\mu \partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\mu \partial y}{\partial y}\right) + Sy$$

Energy equation:

$$-\frac{\partial}{\partial x}(\rho u_x H) + \frac{\partial}{\partial x}(\rho u H) + \frac{\partial}{\partial y}(\rho v H) = \frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K\frac{\partial T}{\partial y}\right) + S_H$$

Effect of surface active element can be taken into account using:

$$\frac{\partial \gamma}{\partial T} = -A - R\Gamma_s \ln(1 + K\alpha_i) - \left(\frac{K\alpha_i}{1 + K\alpha_i}\right)\left(\frac{\Gamma s\, \Delta H^\circ}{T}\right)$$

Results:

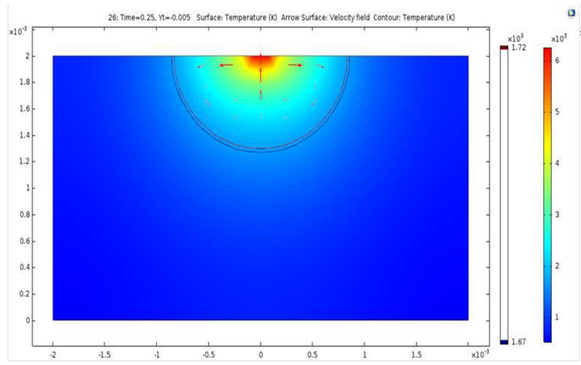

Figure 2. ∂γ/∂T= -0.005 N/mK

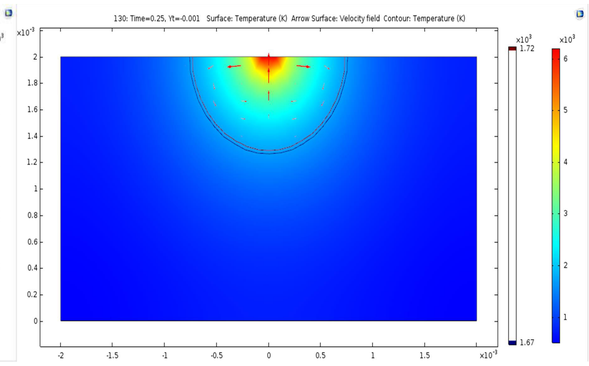

Figure 3. ∂γ/∂T= -0.001 N/mK

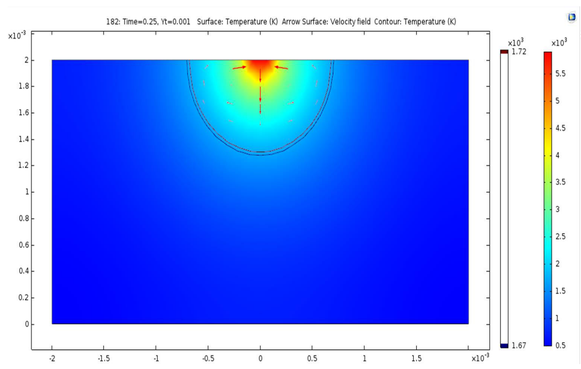

Figure 4. ∂γ/∂T= 0.001 N/mK

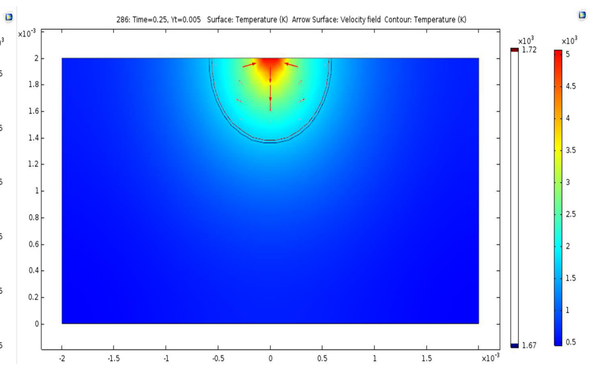

Figure 5. ∂γ/∂T= 0.005 N/mK

Evolution of flow pattern and melt pool shape ∂γ/∂T.

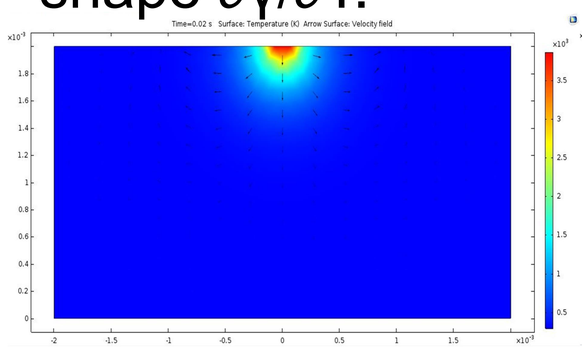

Figure 6.Flow pattern at t = 0.02 s

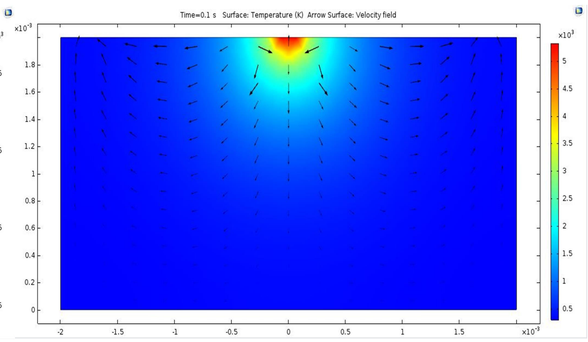

Figure 7. Flow pattern at t = 0.1 s

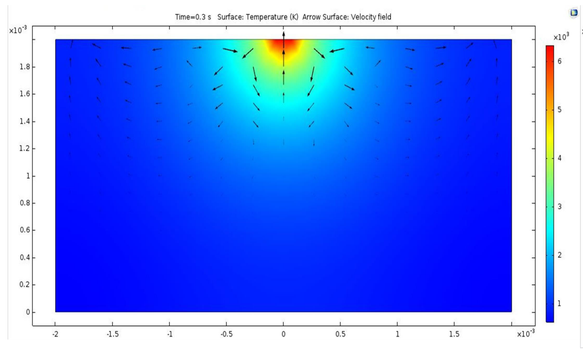

Figure 8. Flow pattern at t = 0.3 s

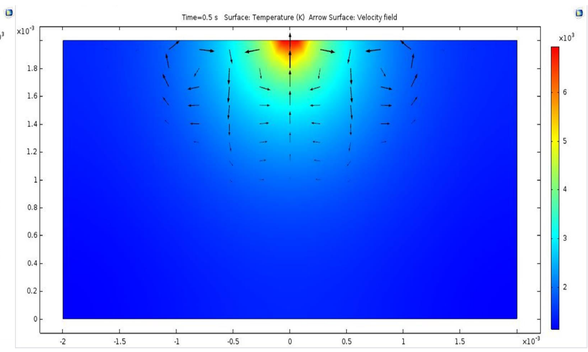

Figure 7. Flow pattern at t = 0.5 s

Effect of sulfur concentration on the flow pattern within melt pool.

Conclusions: Results shows how Marangoni flow develops, evolution of melt pool shape and the dependence of flow pattern on the sign of surface tension gradient. Later, the dependence of surface tension gradient on the surface active elements concentration is analyzed. Simulation results of flow fields are shown for a chosen concentration.

References:

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2. Zhao Y., Lei Y., Shi Y., “Effects of surface active elements sulfur on flow patterns of welding pool”, J. Mater. Sci. Technol., vol 21 no.3, 408-414, (2005)

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