CCC AUNNAL REPORT

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Scale Layer Thickness Measurement and Effect on Heat Transfer Calculation by CON1D

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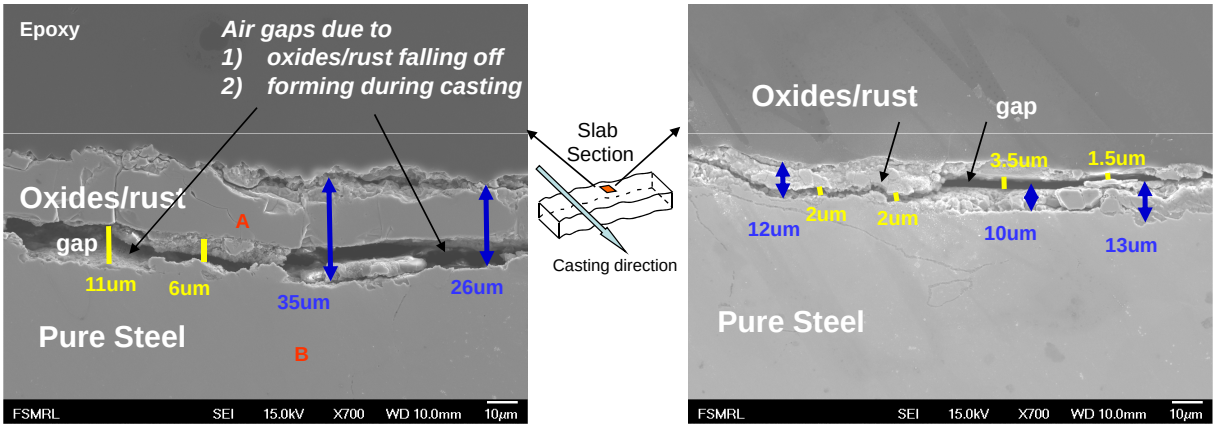
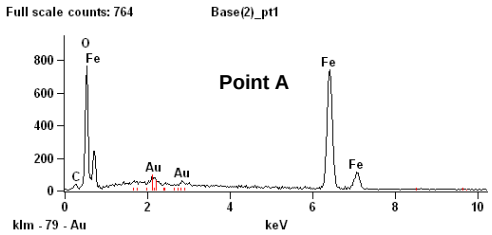
Objective

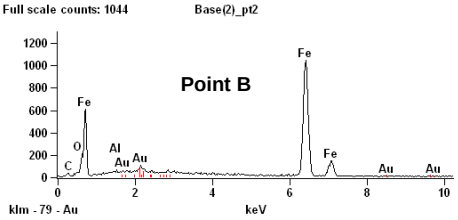
- Quantify the effect of scale layer thickness on heat transfer during continuous casting by using Con1d.
- Make Con1d prediction of shell thickness or shell surface temperature more accurate.

Scale Layer Thickness Measurement by SEM
Top Surface (Center of Slab)





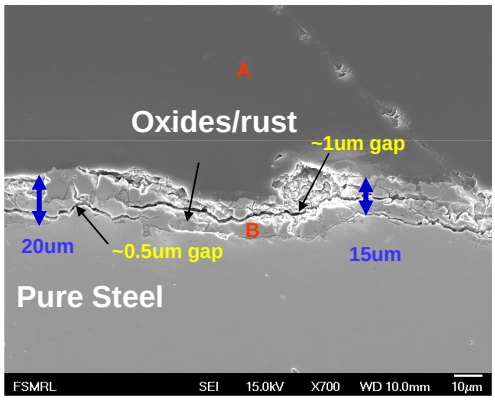
EDS

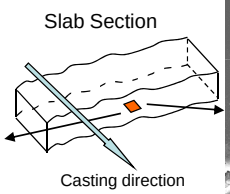


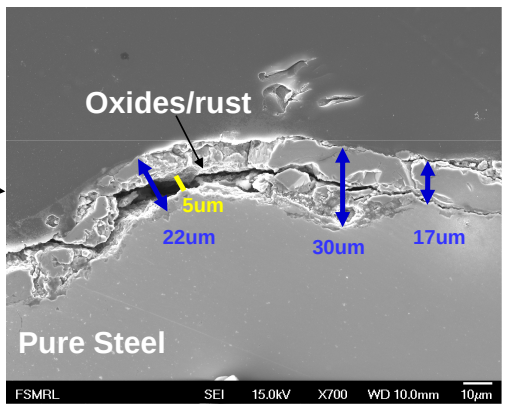
O and Fe are major Elements => Oxides

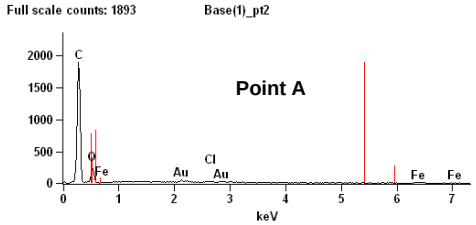
Fe is major elements => pure steel

Scale Layer Thickness Measurement by SEM
Bottom Surface (Center of Slab)

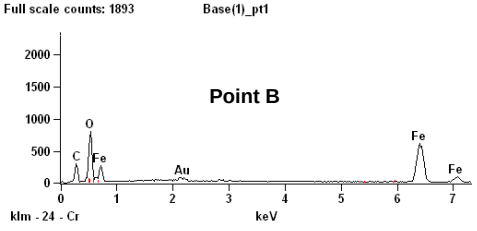








EDS



C, O and Cl are major elements => Epoxy

O and Fe are major elements => Oxides/rust
(C element comes from epoxy falling over on the steel during polishing)

Conclusions about Scale Layer

- Thickness of the scale layer on the top surface in the center of the slab is 10 um – 35 um.
- Thickness of the scale layer on the bottom surface in the center of the slab is 15 um – 30 um.
- Air gap size is 0 um – 11um.
- Air gap inside the scale layer (oxides/rust) probably comes from:
  - scale layer being brittle and easy to fall off during polishing.
  - formation during casting

Scale Layer Included in Con1d

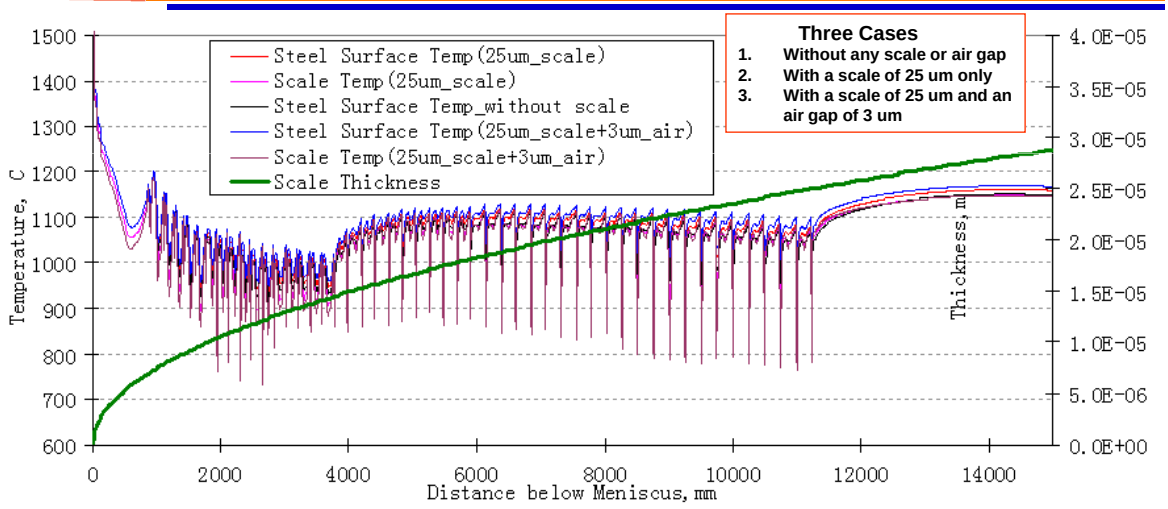
- Steady state model of scale layer heat transfer is used, specifically: $\frac{1}{h_{eff}} = \frac{1}{h_{spray}} + \frac{d_{scale}}{k_{scale}}$
- Scale layer thickness growth function:

$$d_{scale} = Kt^n$$

  - K is constant and obtained by total scale thickness and total time (from meniscus to the end of the caster)
  - t is time
  - n is constant and chosen to be 0.5 in the following simulations

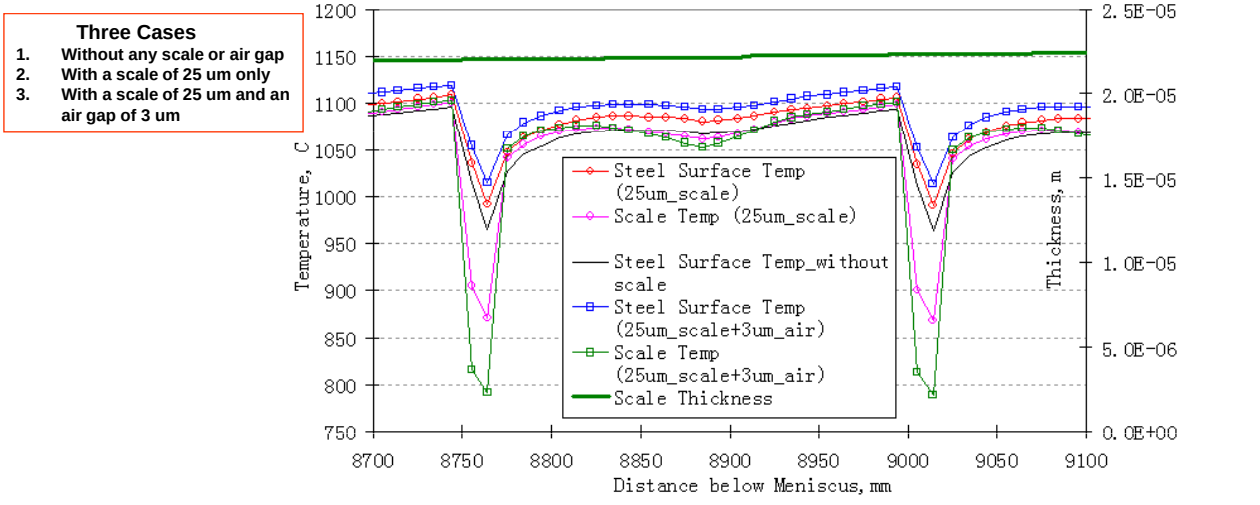
- Convert air gap to scale layer thickness
  - Air gap thermal resistance: d_{air}/k_{air} = 3 um / 0.06 W/mK =50 um^2K/W
  - Equivalent scale layer thickness:
    - $d_{scale\_eqvi} = (d_{air}/k_{air} * k_{scale})$ = 50 um^2K/W * 0.5 W/mK = 25 um

Slab Inner Surface Temperature Comparison



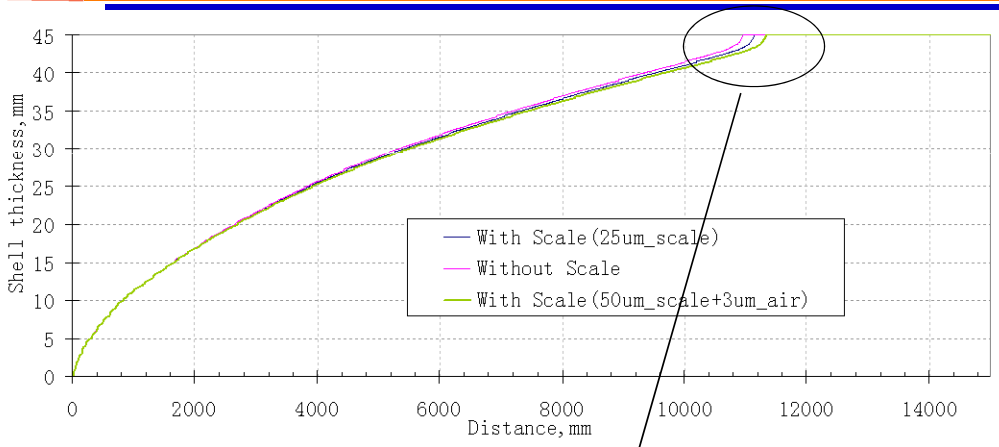
- The scale thickness at the exit of the caster is 25 um and air gap size is taken to be 3 um.
- Scale thermal conductivity is 0.5 W/mK in these cases.
- Predicted scale surface temperature for 25 um scale layer case (case 2) fluctuates ~ 230 ^{o}C.
- Predicted scale surface temperature for 25 um scale layer with 3 um air gap case (case 3) fluctuates ~ 300 ^{o}C.

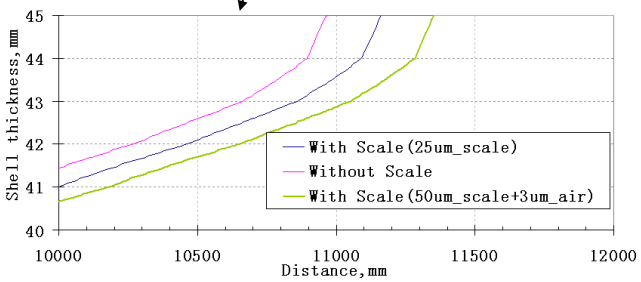
Zoom-in: Temperature Comparison



- Steel surface temperature with scale increases a little (~25 ^{o}C [2.4%] for case 2 and ~<40 ^{o}C [3.8%] for case 3) than the temperature in case 1.
- For case 2, scale surface temperature is ~70 ^{o}C lower when it is under rollers and scale temperature is 5 ^{o}C less than case 1 when it is beneath the sprays.
- For case 3, scale surface temperature is ~170 ^{o}C lower when it is under rollers and scale temperature is 15 ^{o}C less than in case 1 when it is beneath the sprays.

Metallurgical Length Comparison





- **Metallurgical length is increased by ~200mm by 25um scale layer in case 2.**
- **Metallurgical length is increased by ~400mm by 25um scale layer combining with 3 air gap in case 3.**
- **This is important in whale formation prediction.**

Discussion

- Steel surface temperature (under sprays) increases less than 40 ^{o}C for both case 2 and 3.
- Perform rough calculation to check:
  - 1000 W/m^{2}K drops 5% to 952.3 W/m^{2}K with a scale layer of 25um

$$\frac{1}{h_{eff}\,(W/m^2K)} = \frac{1}{1000(W/m^2K)} + \frac{2.5\times10^{-5}(m)}{0.5(W/mK)}$$

Typical steel surface heat transfer coefficient range: 100 -1500 W/m^{2}K

Conclusions

1. Steel surface temperature with scale increases only a little (~25 ^{o}C [2.4%] for case 2 and ~40 ^{o}C [3.8%] for case 3) than the temperature in case 1.
2. Metallurgical length is increased by ~200mm by 25um scale layer in case 2.
3. Metallurgical length is increased by ~400mm by 25um scale layer combining with 3 air gap in case 3.
4. Scale surface temperature decrease (under sprays) is less than 15 ^{o}C for both case 2 and 3.
5. This cannot explain the big decrease in measured pyrometer measurement relative to CON1D predictions

Acknowledgement

- Continuous Casting Consortium

  (ABB, Arcelor-Mittal, Baosteel, Corus, LWB Refractories, Nucor Steel, Nippon Steel, Postech, Posco, ANSYS-Fluent.)
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