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Investigation of Subsurface Hooks in Ultra-low Carbon Steels: Metallurgical Analysis

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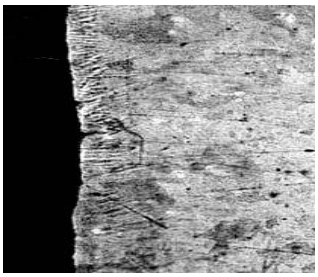
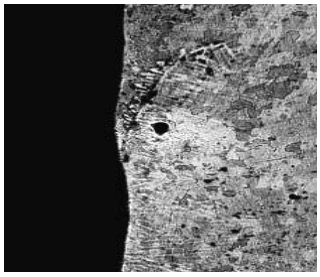
- Mr. Go-Gi Lee, POSTECH

Importance of initial solidification

- Initial solidification behavior affects the formation of oscillation marks (OM) and subsurface hooks
- Initial solidification features related to surface quality problems
  - **Deep oscillation mark** : Transverse crack formation
  - **Deep hook** : Easy Entrapment of mold flux and inclusion-laden gas bubbles



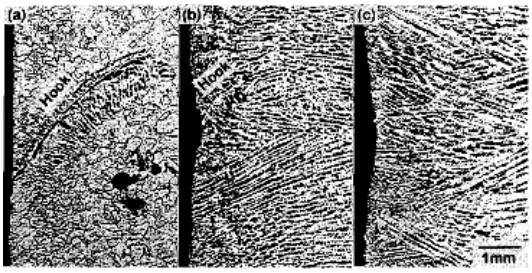
< Transverse Crack at valley of OM>



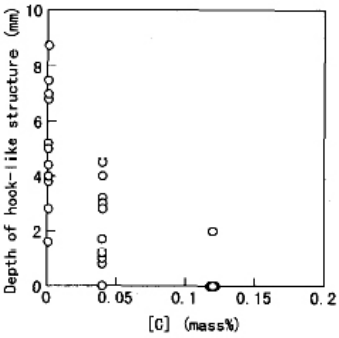
< Bubble captured by hook >

Hook problems in ultra-low carbon steels

- Ultra-low carbon steel for automobile demands high level of quality
- Hook problems increase with decrease in carbon contents



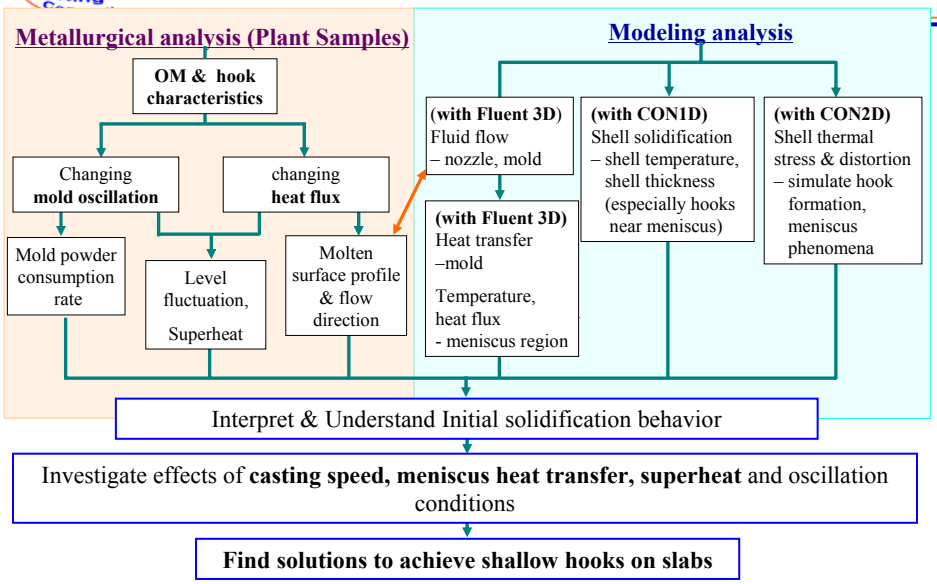
(a) 0.002 % C **(b) 0.033 % C** **(c) 0.100 % C**



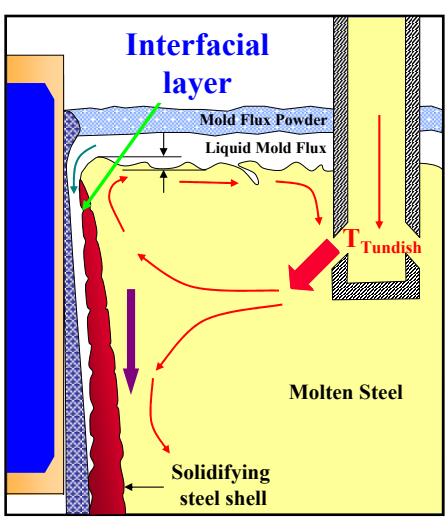
< Relationship between hook and carbon contents of steel>

Ref.) H. Yamamura et al., ISIJ International, 1996

Objectives (Larger project)



Which measurable parameters are related to hook formation?



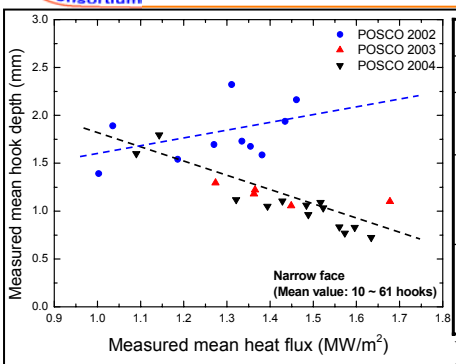
- In molten steel pool

- Casting speed
- Superheat ($T_{Tundish} - T_{Liquidus}$)
- Flow pattern in liquid pool
- Surface level fluctuation

- In interfacial layer

- Mold oscillation (frequency)
- Oscillation mark (OM)
- Mold powder consumption rate

Relationship with mean heat flux



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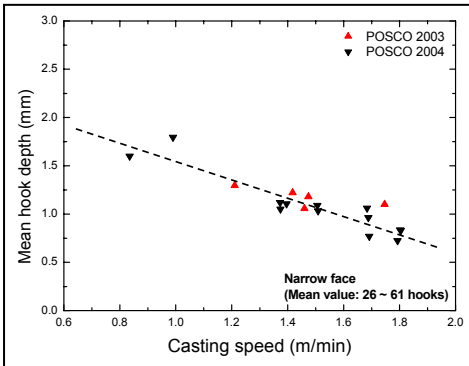
Year	2002	2003~ 2004
V_C (m/min)	~ 1.45	0.84 ~ 1.80
F (cpm)	106 ~ 209 (Independent)	98 ~192 F = function (Vc)
Relation between V_C and q	**Independent**	**q =function (V_C)**
D_{Hook} with increasing of $q_{Measured}$	↑	↓

V_C : casting speed, F : oscillation frequency, D_{Hook} : Mean hook depth
$q_{Measured}$: Measured mean heat flux calculated from temperature difference of cooling water

Phenomena in molten steel pool → **Both of $q_{Measured}$ & D_{Hook} are affected by many other operation parameters** ← **Phenomena in interfacial layer**

Relationship with casting speed



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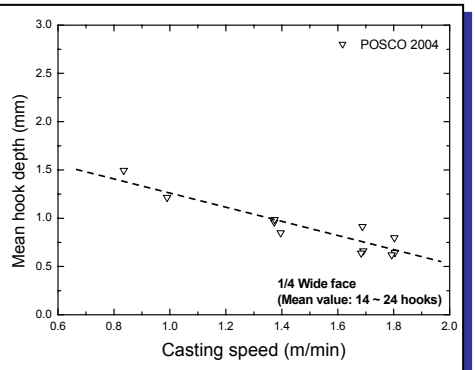

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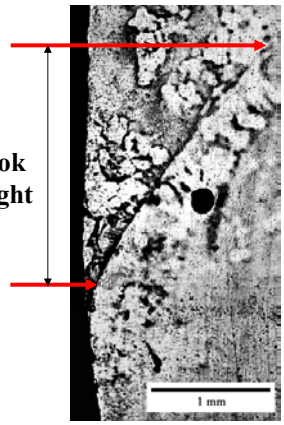
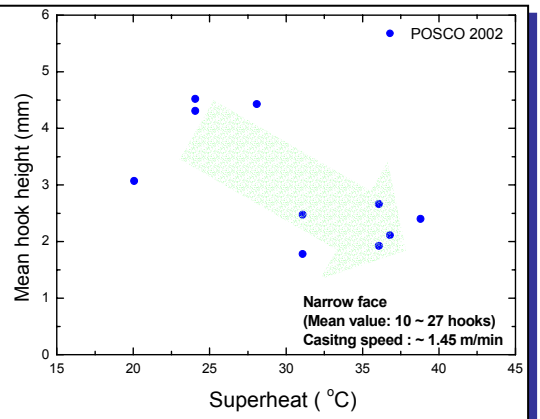
Casting speed ↑ → Mean hook depth ↓

Relationship with superheat ($T_{Tudnish} - T_{Liquidus}$)





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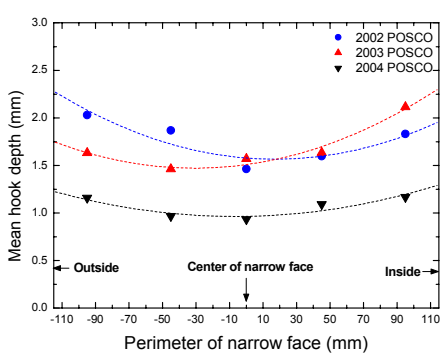
Superheat ↑ → Mean hook height ↓

Relationship with flow pattern in liquid pool



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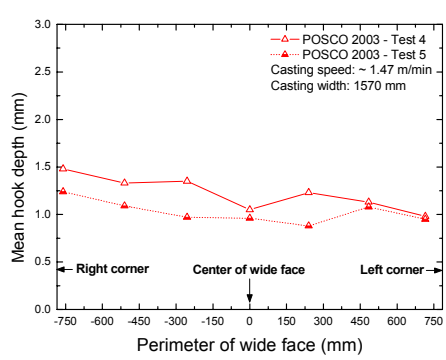

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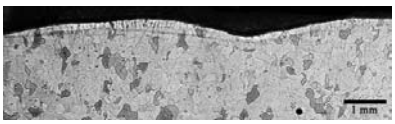
Hook depth varies around mold perimeter: deeper at narrow face; deepest at corners

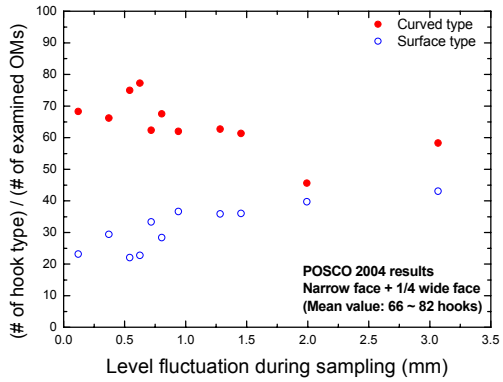
Relationship with surface level fluctuation

< Curved type hook>

Slab quality improvement

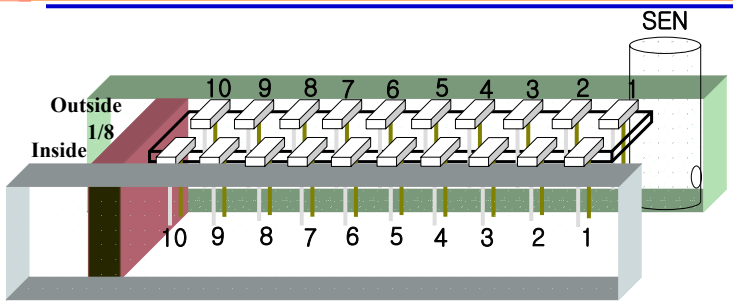


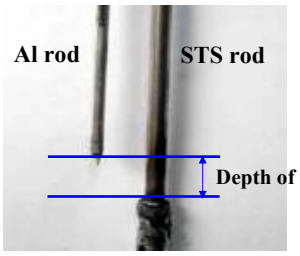
< Surface type hook>



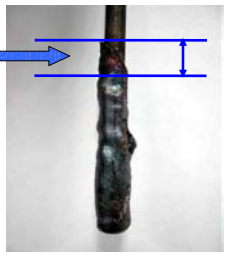
Level fluctuation ↑ → Probability of curved hook ↓

Measuring surface profile & slag depth using nail boards





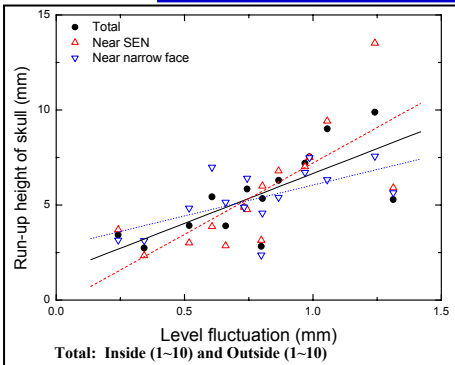
Direction of surface molten steel flow



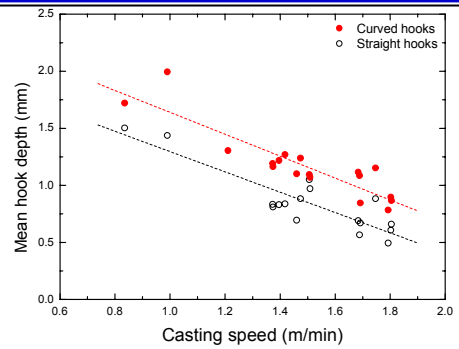
Run-up Height

& Skull angle: increase with surface velocity of molten steel

Relationship between level fluctuation and surface velocity of molten steel



Total: Inside (1~10) and Outside (1~10)
Near SEN: Inside (1~5) and Outside (1~5)
Near narrow face: Inside (6~10) and Outside (6~10)



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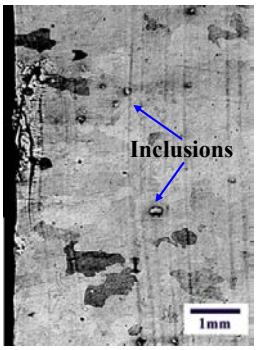
Level fluctuation ↑ → Surface velocity of molten steel ↑
→ Local superheat ↑ → Probability of curved hook ↓
→ Influence of hook on slab quality ↓

Relationship between level fluctuation and slab quality

Sample No.	B31075-04	B31077-04
Level fluctuation (mm)	1.99	0.94
Casting speed (m/min)	1.69	1.68
Occurrence of hooks (%)	86	98
Occurrence of surface hooks (%)	37	17
Occurrence of curved hooks (%)	49	81
Mean hook depth (mm)	0.77	1.48
Max. hook depth (mm)	1.48	1.92

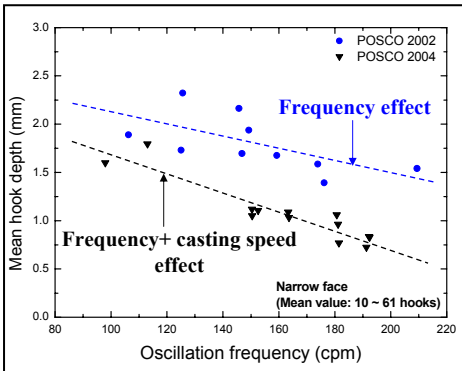


< B31075-04 >

< B31077-04 >

High level fluctuation → **Deceasing hook depth** / **Increasing other problems (e.g. Mold powder entrapment)** → **Proper amount of surface turbulence may improve for slab quality**

Relationship with mold oscillation

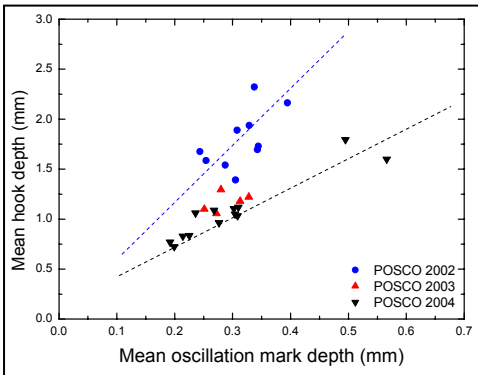


< Narrow face results>

Year	2002	2004
V_C (m/min)	~ 1.45	0.84 ~ 1.80
F (cpm)	106 ~ 209	98 ~192
Relation between V_C and F	**Independent**	**F = 97.5*(V_C) +16.5**
Parameters to decrease hook depth	Increasing Frequency	Increasing Frequency + casting speed
$T_{solidification}$ of used mold flux (°C)	1149	1101

Oscillation frequency ↑ → Mean hook depth ↓
(Frequency + Casting speed) ↑ → Mean hook depth ↓↓

Relationship with oscillation mark depth



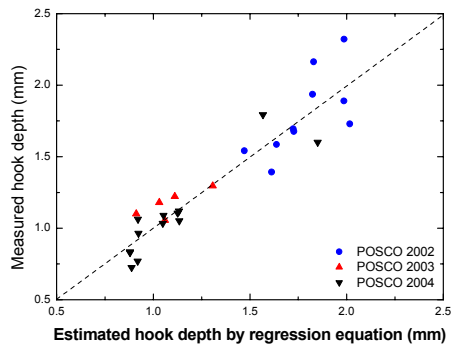
< Narrow face results>

Year	2002	2003~ 2004
V_C (m/min)	~ 1.45	0.84 ~ 1.80
F (cpm)	106 ~ 209	98 ~192
Relation between V_C and F	**Independent**	**F =function (V_C)**
Mold powder	KF-03	KF-09
Viscosity at 1300°C (in Poise)	3.21	2.62

Mean hook depth ↑ → Oscillation mark depth ↑
(Mold powder properties affect OM & hook depth)

Simple empirical equation with experimental results

	Operation parameter	Effect of increasing parameter on hook depth
V_C	Casting speed (m/min)	↓
F	Oscillation frequency (cpm)	↓
$T_{Tundish}$ - $T_{Liquidus}$	Superheat (°C)	↓
L	Level fluctuation (mm)	↓
$T_{soildifcation\ of\ mold\ flux}$	Solidification temperature of mold powder	↑



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$$\text{Predicted Mean Hook Depth} = 2.194 \times Vc^{-0.657} \times F^{-0.432} \times (T_{Tundish} - T_{Liquidus})^{-0.156} \times L_F^{-0.00191} \times (T_{Solidification\ of\ mold\ flux})^{11.38}$$

Conclusions

- Heat flux at meniscus is not directly related mean heat flux
- Higher casting speed and higher superheat temperature both deliver more superheat to meniscus and decrease hook growth
- Hook depth variation along mold perimeter: increases at narrow face and is maximum near mold corners
- Casting conditions with higher level fluctuations have more occurrences of surface hooks but fewer curved hooks
- Hook influence can deceases with high level fluctuation combined with higher local superheat
- Some amount of surface turbulence (and corresponding local superheat) is needed to minimize hooks and their slab defects
- Increasing oscillation frequency shortens solidification time, negative strip time, and positive strip time. This results in thinner, shallower hooks and shallower oscillation marks, which should improve surface quality
- Mold powder properties greatly affect hook formation