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Disstec – 'Inclusion Control Through Secondary Steelmaking and Tundish'

27th September, 2017

BFI | MPI Materials Processing Institute | CRM GROUP | swerea MEFOS | RINA CONSULTING

Projects Covered in this Presentation

- ‘Optimisation and evaluation of different secondary steelmaking routes to achieve high quality strip steel’ (7210-PR-332)

- ‘Active tundish metallurgy (ActuM)’ (RFSR-CT-2008-00006)

‘Optimisation and evaluation of different secondary steelmaking routes to achieve high quality strip steel’

(7210-PR-332)

Content

Project Partners

• Voestalpine Stahl GmbH	Austria – Coordinator
• Corus Ijmuiden	Netherlands
• Stahlinstitut VDEH	Germany
• Thyssen Krupp AG	Germany
• OVAKO Bar Oy Ab	Finland
• Huttenwerke Krup Mannesmann GmbH	Germany
• (formerly) Saltzgitter Mannesmann, Forschung GmbH	Germany

Objective

Better inclusion control

1. Improve capability for Ultra Low Carbon- Interstitial Free (ULC-IF) steels (C<40ppm, N<35ppm)
   - Exposed automotive steels
   - Ti stabilised; Ti/Nb stabilised; or Non-stabilised
   - High level of formability
   - Ca treatment NOT allowed - Highest level of surface finish quality (O5)
   - Need to generate correct inclusion type (location; quantity; morphology; and size)
     - *Requirement for good castability*
     - *Long sequence lengths*
     - *Low rejection rates*

2. Improve capability for Low Carbon Aluminium Killed (LCAK) steels
   - NOT exposed automotive steels eg pressure cylinder for brake discs or cone belt discs
   - Ca treatment is allowed - lower level of surface finish quality (O3)
     - *Requirement for high Calcium yield*
     - *Minimal amount of Calcium use*
     - *Good reproducibility*
     - *Low level of 'clogging' and refractory wear at caster refractories*
     - *Stable caster operation*

Process Stages

Process Stages Used	Voest	TKS Ox1	CORUS	HKM
Hot Metal Desulfurization	3 stations Co-Injection: CaC_2/Mg	2 stations Co-Injection: Mg/CaC_2/CaO	2 stations Co-Injection: Mg/CaO	2 stations Co-Injection: Mg/CaO
Converters	3 x 160, LD-type	2 x 380t, LD-type	3 x 325t, LD-type	275 x 2t LD-type, change vessels
Secondary Metallurgy Facilities	2 x RH 3 x Ladle Furnace	1 x RH-Top-Lance 2 x stirring station 1 CAS-OB	1 x RH-OB 2 x stirring station 1 x ladle furnace	2x 2 VD 3 x stirring station
CC Maschines (Conventional)	**Caster no. 5** No. of strands: 1 vertical bending type Slab width: 740-1600 mm Slab thickness: 215 mm	**Caster no. 1** No. of strands: 2 vertical bending type Slab width: 1800-2600 mm Slab thickness: 215 mm	**Caster no. 1** No. of strands 2 curve Slab width: 950-1950 mm Slab thickness: 190-225 mm **Caster no. 2** No. of strands: 2 curve Slab width: 950-2150 mm Slab thickness: 225 mm	**Caster no. 1** No. of strands 4 curve type Slab width: 325-675 mm Slab thickness: 260 mm
CC Maschines (DSP)			**Caster no. 1** No. of strands: 1 Slab width: 750-1560 mm Slab thickness: 70 mm	
Examples of products:	Ti stabilized ULC-IF	IF, ULC, DDQ, LCAK	IF ULC (EDDQ), HSLA (HSS), LCAK (DDQ)	LCAK, LCAK (vac.)

Colors used

Route for all Steels	Route Steel DSP with CaFe	Route Steel HSLA	Route Steel Vacuum Treatment	Route Steel LCAK

Abbreviations

DSP: Direct Strip Plant	DDQ: Deep drawing Quality Steel	EDDQ: Extra Deep Drawing Quality Steel	HLSA: High Strength Low Alloyed Steel	HSS: High Strength Steel
IF: Interstitial Free Steel	LCAK: Low Carbon Alluminium Killed Steel	ULC: Ultra Low Carbon Steel		

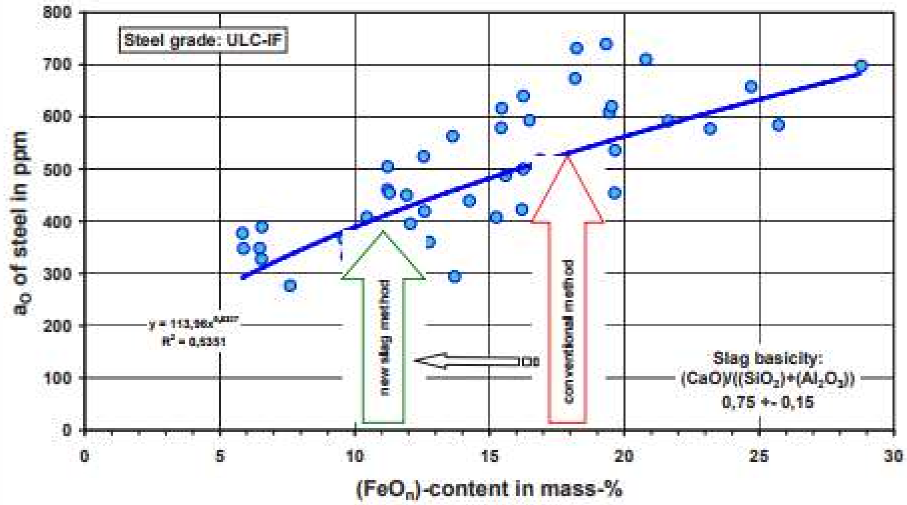
Slag Treatment Trials

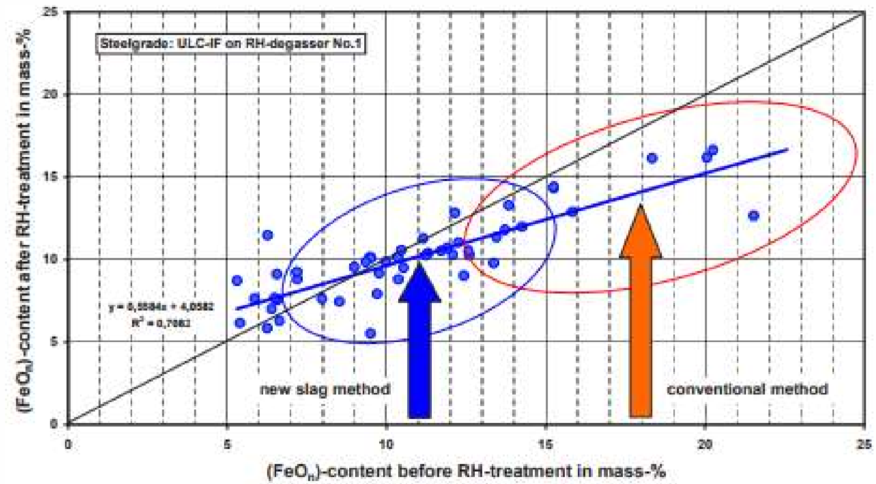
- Usually, no slag modification treatment is applied for ULC/IF grade
- Avoidance of alumina generation is the main focus for ULC/IF grades, with production restrictions including:
  - *Avoiding cooling scrap additions during RH treatment and after Al deoxidation*
  - *No chemical heating after Al deoxidation*
  - *No bottom stirring of the heat after RH treatment*
  - *RH treatment has to be the last process before sending to the caster*

Slag Treatment Trials

Optimisation of ladle slag composition

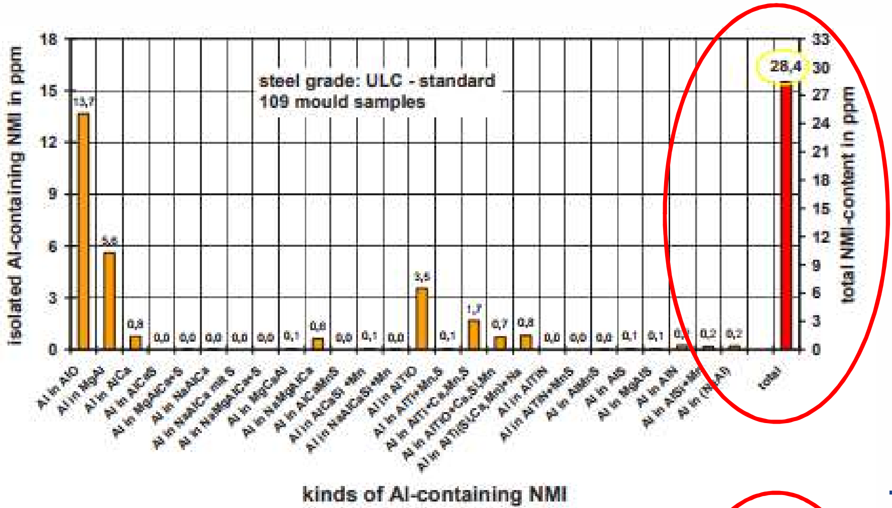
- For a Ti-stabilised ULC IF steel, a slag deoxidant (Foseco BDX-20) was applied to the slag before RH treatment
  - *Aim was to decrease ladle slag (FeO_n) content*
  - *Reduce re-oxidation of dissolved aluminium*
  - *Lower the total oxygen level*
- Expected improved castability
  - *a_o ≈> 400ppm*
  - *(FeO_n) reduced from ~17% to ~11%*
  - *Reduced total oxygen content*
  - *Better internal cleanness*



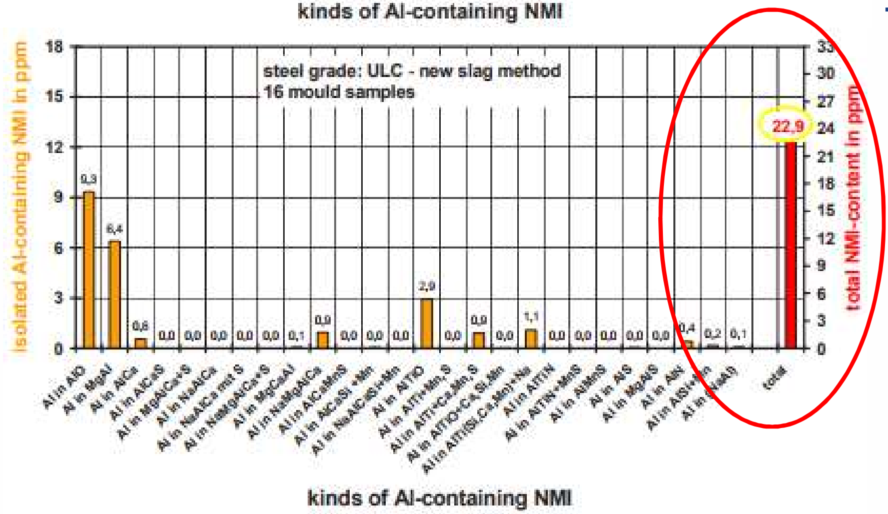


Steel Sample Cleanness With and Without Slag Conditioning

Normal Practice



Slag Conditioning Practice

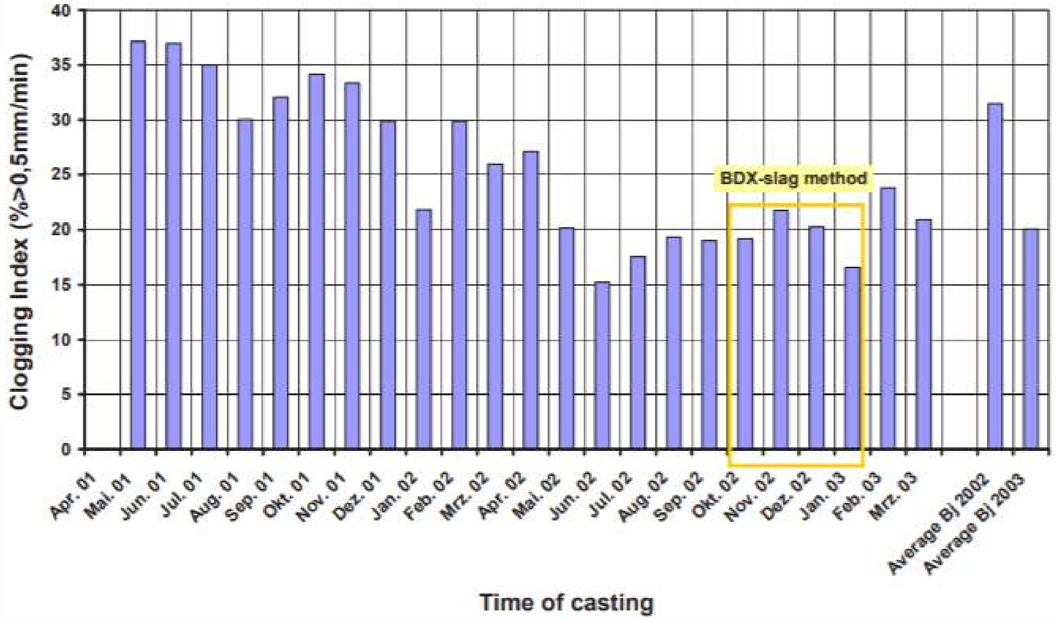


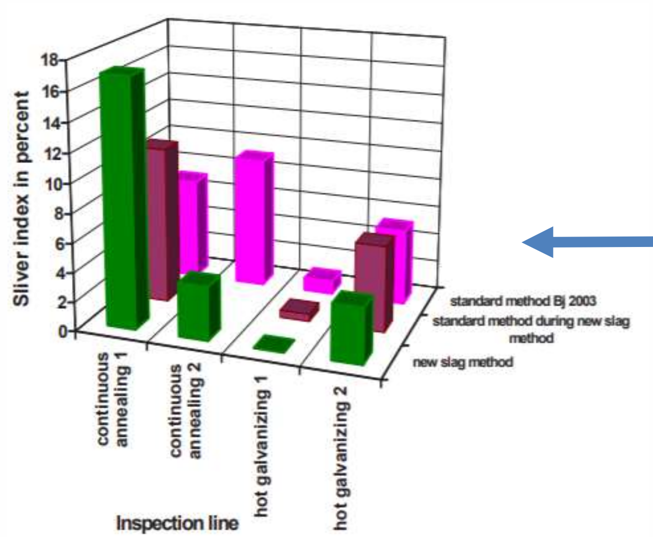
Total NMI's: 28.4 ppm → 22.9 ppm

Slag Treatment Trials

Optimisation of ladle slag composition

Castability was not significantly improved during the three month trial





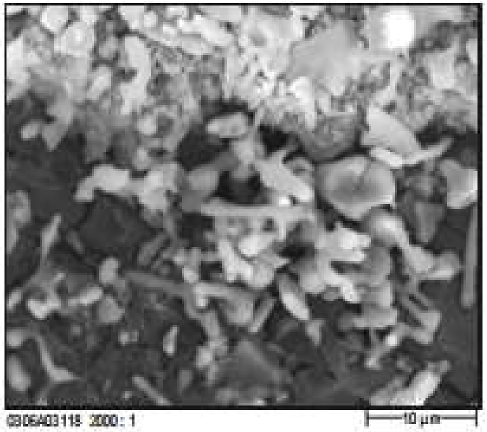
- Sliver Index at hot galvanising No. 2 route was reduced by ~30% during the three month trial
- Slag modification is a high cost procedure
- Decision to implement the procedure is a strategic one

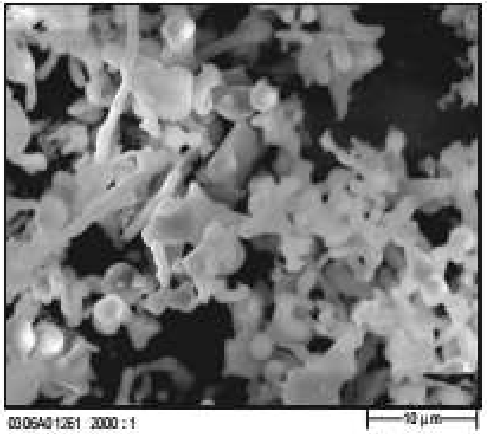
Alumina Inclusions

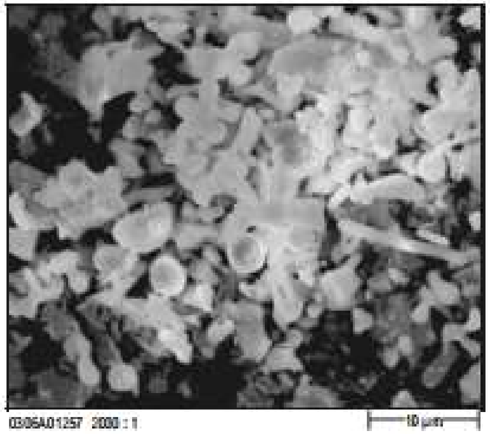
Morphology

- An investigation into inclusion morphology at different processing stations was carried out.

- In the vacuum degasser sample, inclusions were found to be >10 µm and of a coarse, coral-shaped nature.

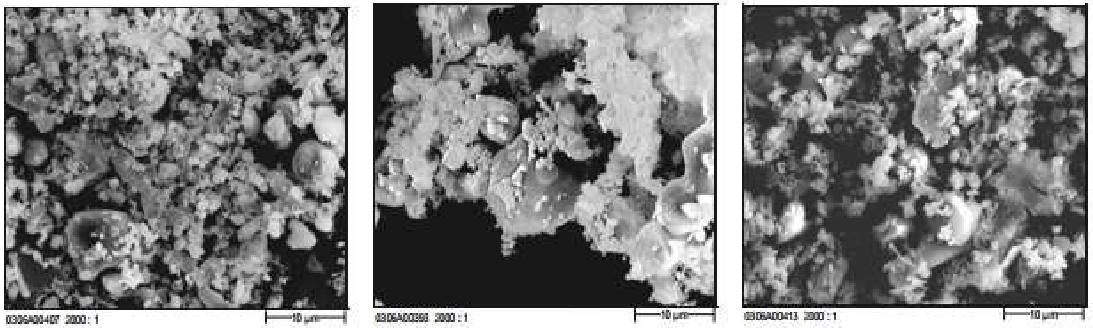






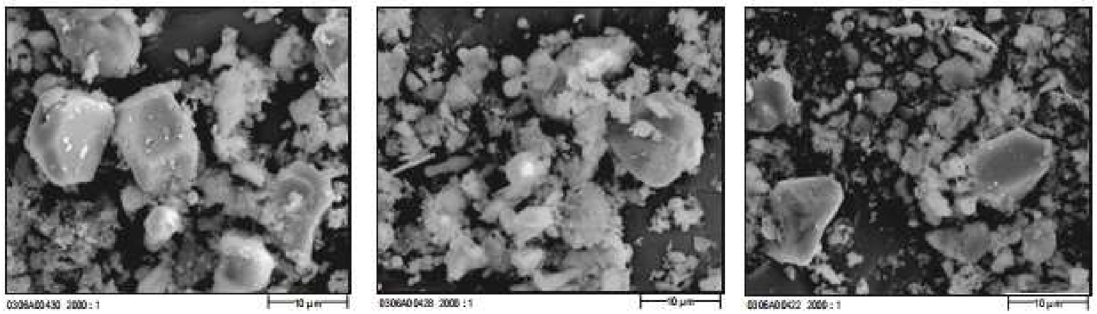
Alumina Inclusions

- In the tundish and mould samples, smaller inclusions were found with fine crystalline structures. It was observed that some small crystals seem to grow on larger crystals.



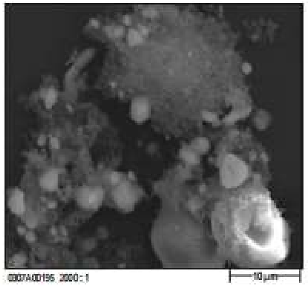
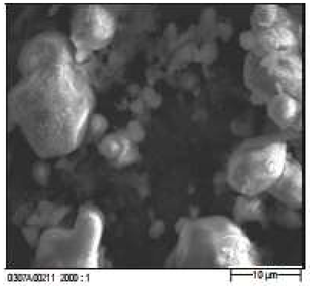
Tundish

Mould

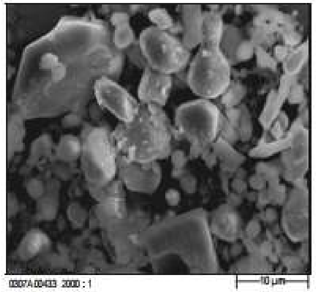
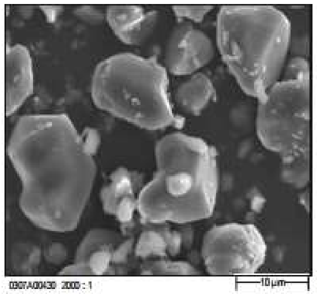
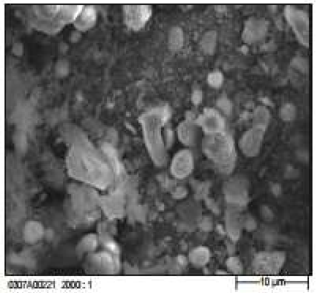


Alumina Inclusions

- In the online slab sample, the inclusions are larger than in the mould and have round, globular shape.

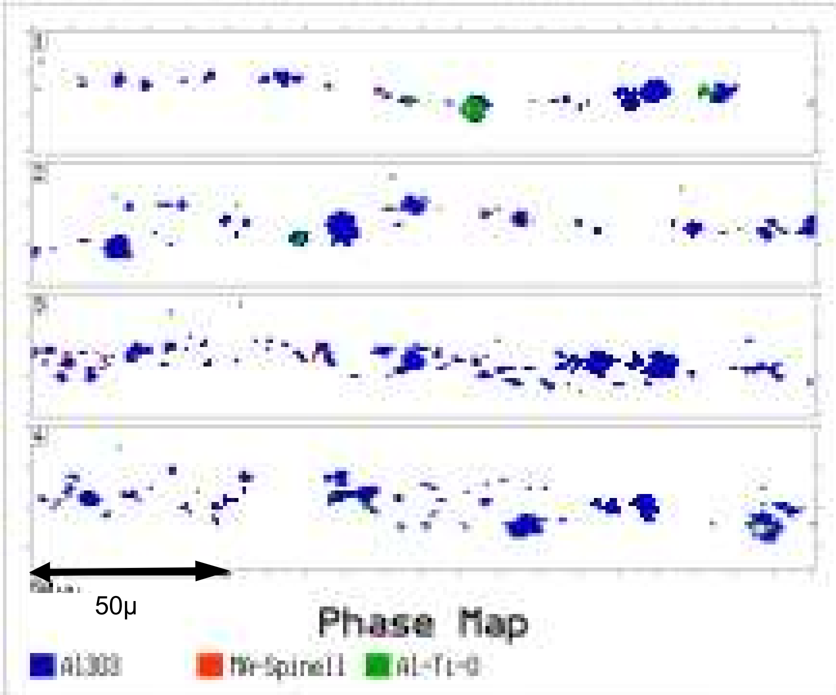
- In the rolled slab sample, the inclusions look more crumbled and not as globular. This could be due to deformation processes during rolling.

Surface Defects

- Main surface defects for strip grades are slivers, with the most common resulting from entrapment of mould slag:
  - *80% mould slag inclusions*
  - *10% alumina inclusions*
  - *10% mixtures of mould slag/ alumina / ladle slag / refractories ....*

- Working theory:
  - *Reducing the onset of clogging will produce a stable mould level which will then lead to fewer surface defects*



Phase Analysis Results												
Phase		Al2O3	SiO2	Fe	CaO	Na2O	MgO	Zr	MnO	TiO2	K2O	∑ %
Al2O3	m-%	79.42	0.01	13.00	0.05	0.04	0.06	0.71	0.12	0.30	0.03	93.74
	mol%	99.30					0.21			0.49		100.00
MA-Spinel	m-%	45.28	0.07	25.29	0.14	0.02	15.71	0.67	0.25	0.18	0.02	87.63
	mol%	53.38					46.37			0.25		100.00
Al-Ti-O	m-%	68.00	0.02	12.28	0.07	0.22	0.43	1.63	0.18	9.82	0.02	92.67
	mol%	83.50					1.38			15.12		100.00

Phase map of alumina inclusion types inside four sliver defects

Surface Defects

Calcium Aluminate inclusions could derive from:

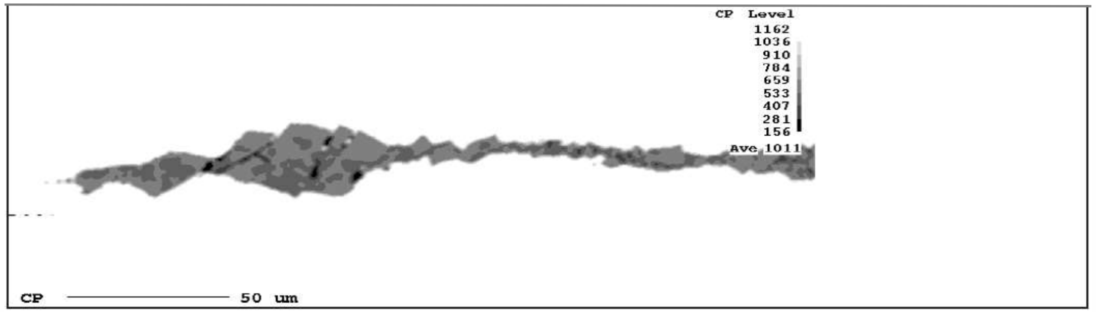
- Mould slag
- Tundish slag
- Ladle slag

No Na_2O detected in inclusion

- *Source is NOT mould slag*

Tracer Trials

- Zirconium silicate tracer added to tundish flux
  - *No zirconium detected in calcium aluminate inclusion cluster*
  - *Source is NOT tundish slag*



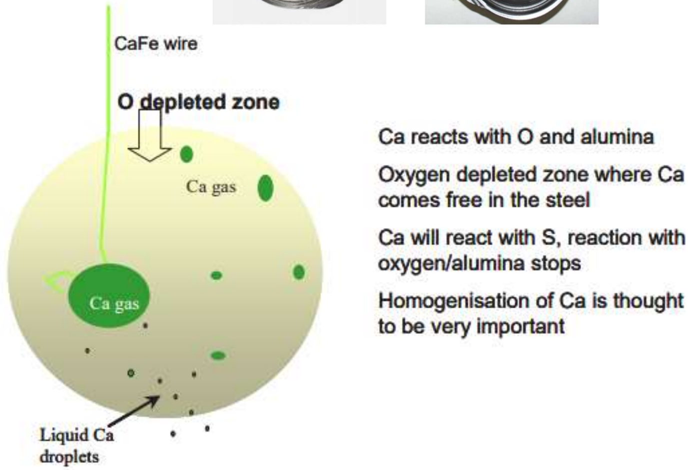
Calcium Aluminate Inclusion in Cold Rolled Sheet

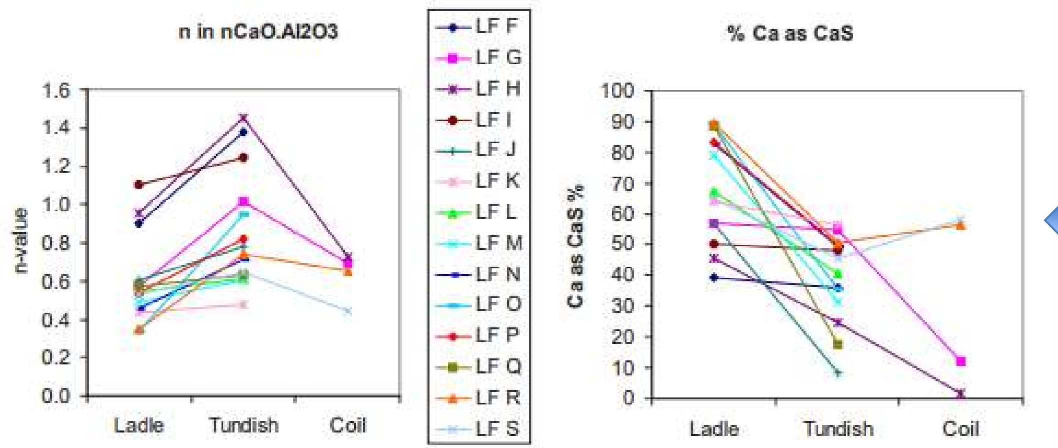
- Source of inclusion is ladle slag

Control of Inclusions by Ca Treatment

LCAK Steel

- Ca treatment is allowed for LCAK steel due to less stringent surface finish quality requirements
- Trial samples taken before, during, and after Ca treatment
- Ca wire injection
- $CaO.Al_2O_3$ and CaS start forming simultaneously during Ca injection





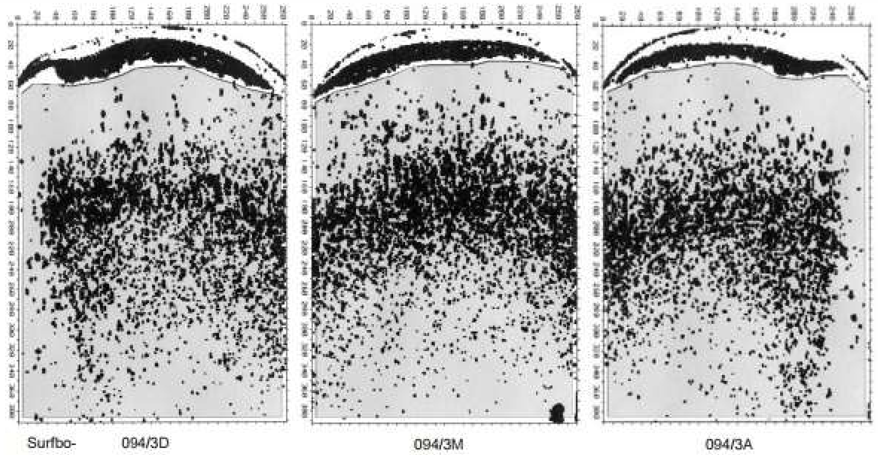
- Evolution of Calcium Aluminate
  - *Requires correct amount of Ca to be injected*
  - *Spike in inclusions at the tundish*
  - *Inclusions agglomerate between ladle and tundish*
  - *Mean inclusion size doubles*

Control of Inclusions by Ca Treatment

MIDAS Tests

- The MIDAS-test provides data on the number and distribution of macro-inclusions
- A section of the cast strand is rolled at right-angles to the direction of casting
- The slab specimen is elongated five-fold in the thickness direction and broadened two-fold in the width direction
- Each test plate (dimensions up to ~300mm x ~400mm) is examined ultrasonically
- Macroscopic cleanness of a conventionally treated LCAK steel and a Ca treated LCAK steel were tested using the MIDAS method

No Ca treatment



Example of Midas test results across the width of a narrow slab

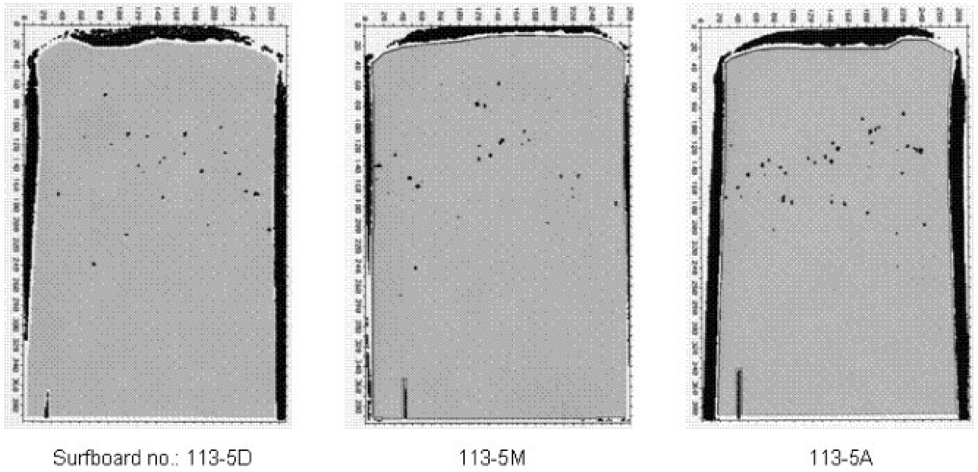
- First heat of a sequence
- Cleanness of the conventionally treated LCAK steel is quite poor
- Defect numbers per sample ranged from 65 to 2000
- Average defect size increases with defect number

Control of Inclusions by Ca Treatment

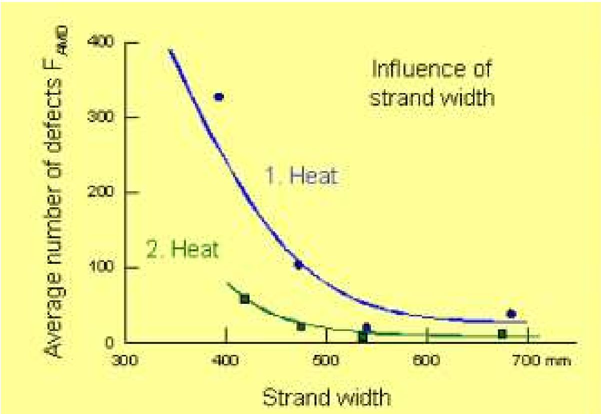
MIDAS Tests

- Macroscopic cleanness of the Ca treated LCAK steel was much improved compared to the standard heats
- For two Ca-treated heats, defect numbers per sample ranged from 2 to 352

Ca treatment



Example of Midas test results across the width of a narrow slab

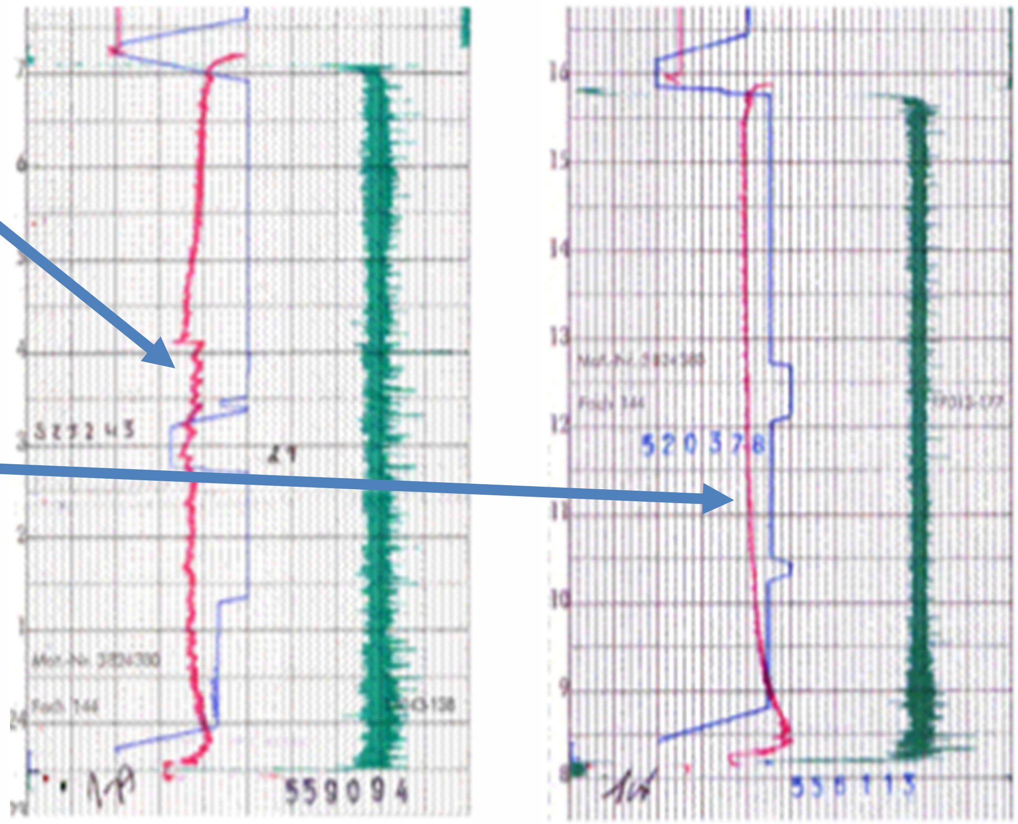


- Both heats followed a trend indicating that increasing slab width reduces the number of defects
- Castability of both heats was excellent

Control of Inclusions by Ca Treatment

- Conventional processing gives poor castability performance causing a limitation to sequence casting
- Castability using Ca treatment is significantly improved
- Length of sequence can be extended from two heats to four heats

Routine secondary metallurgy | Plant trial using CaSi wire



Sequence 591967 | Sequence 591675

Conclusions

- Ladle slag treatment (ULC/IF Grades)
  - *A slag modifier can significantly reduce (FeO_n)-content in the ladle slag after tapping (~17% to ~11%)*
  - *Lower oxygen levels in the ladle slag gives improved steel micro cleanness*
  - *Long term trials showed no significant quality improvement in rolled product*
  - *Ladle slag modification could not be justified on cost grounds*
- Alumina inclusions
  - *Alumina inclusion morphology alters through the process route*
- Surface defects
  - *The source of surface defects may be evaluated through slag tracer trials*
- Ca treatment (LCAK Grades)
  - *$CaO.Al_2O_3$ and CaS form simultaneously during Ca injection*
  - *Inclusions agglomerate between ladle and tundish*
  - *MIDAS tests used to demonstrate improved cleanness*
  - *Significant improvement in castability and sequence length*

’Active Tundish Metallurgy (AcTuM)’
(RFSR-CT-2008-00006)

Content

- Project partners
- Project objective
- Summary of the work done
- Main results
- Industrial trials

Project Partners

• Helsinki University of Technology (TKK) *(Aalto University)*	Finland – Coordinator
• TU Bergakademie Freiberg (TUBAF)	Germany
• Fundación Tecnalia Research & Innovation	Spain
• Gerdau Sidenor Investigaćion y Desarrollo	Spain
• OVAKO Bar Oy Ab	Finland
• Tata Steel Research, Development and Technology	United Kingdom
• Deutsche Edelstahlwerke GmbH (DEW)	Germany

Functions of Tundish Slag

- Prevent re-oxidation
- Thermal insulation
- Absorb inclusions from steel

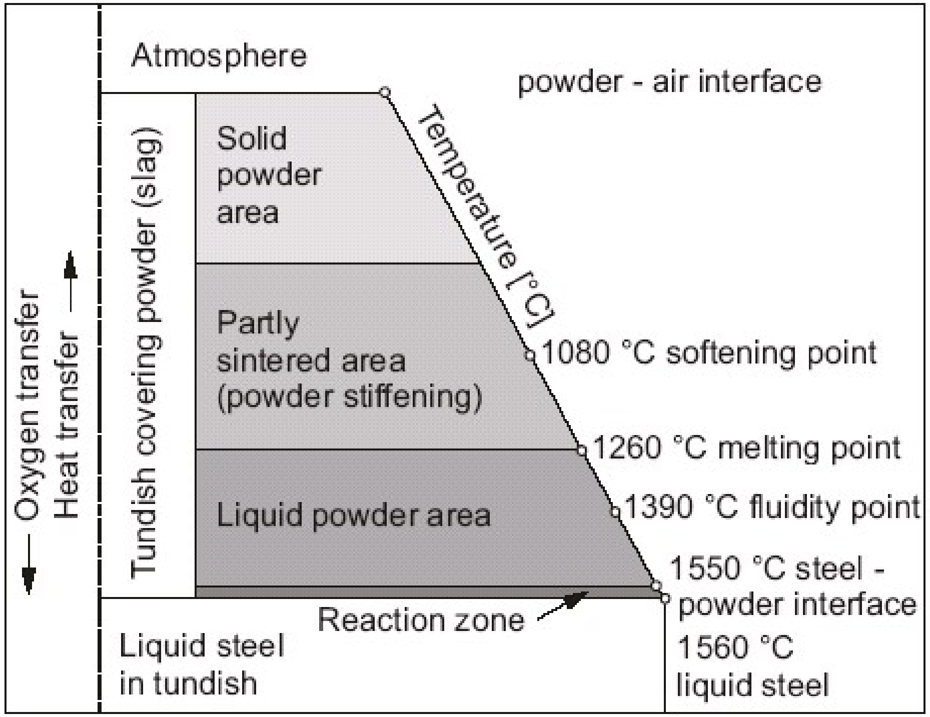


Figure: Kuchař, L.. Prevention of steel melt reoxidation in tundish. Doctoral thesis, TKK, 1994.

Project Objective

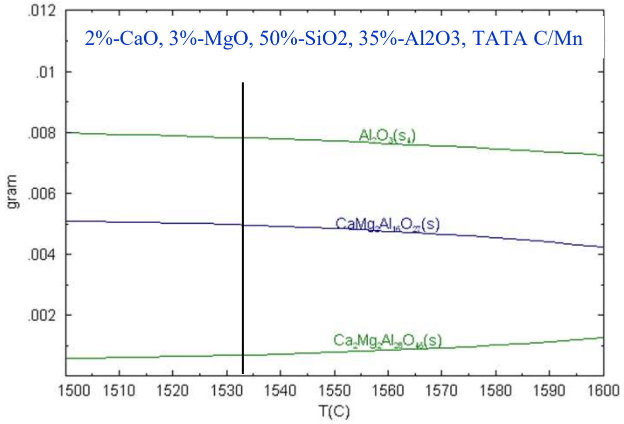
Improve steel cleanness by applying tailored tundish slag with high capacity for efficient absorption of macro- and micro-inclusions from different steels

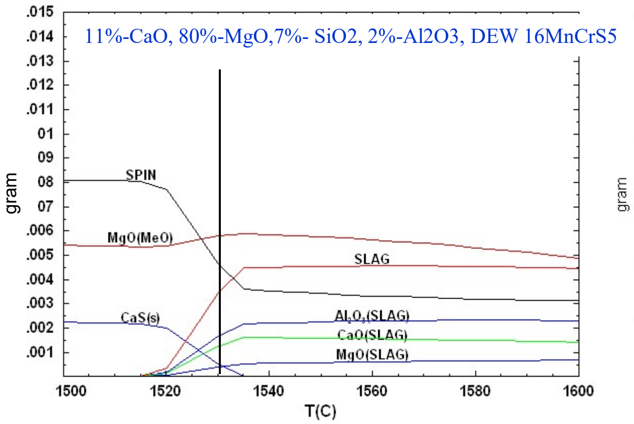
Work Summary

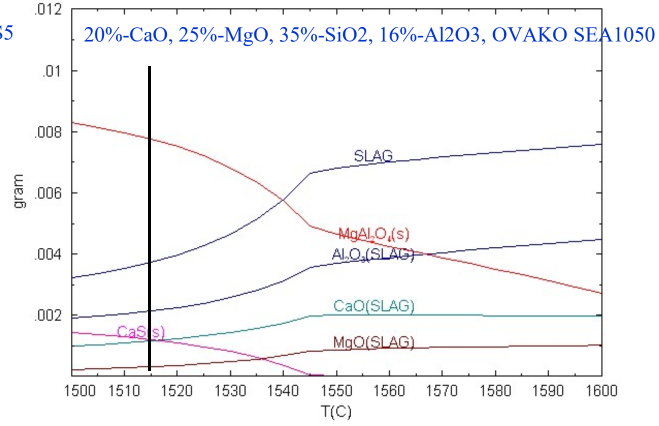
- State-of-the-art on "functionality" of current tundish practice and slag usage in participating steel plants
  - ➢ Evaluate capacity of different tundish slags to absorb inclusions
  - ➢ Propose improved slag compositions for industrial trials
- Thermodynamic and mass balance calculations
  - ➢ Compare steel cleanness results with standard practice
- Fundamental studies on factors influencing inclusion removal and steel cleanness in the tundish
  - ➢ Dissolution investigations
  - ➢ Viscosity, interfacial tension and wettability measurements
  - ➢ Water modelling experiments and CFD simulations
- Experimental tests with proposed new tundish powders carried out in steel plants on laboratory, pilot and industrial scale
- Industrial implementation and evaluation of the developed concepts

Main Results - Evaluation of Potential for Improved Tundish Slag

Thermodynamic calculations showed that: 1) Industrial partners' slags used under standard operating practices were either solid or have only limited capacity to absorb inclusions from steel at tundish temperatures

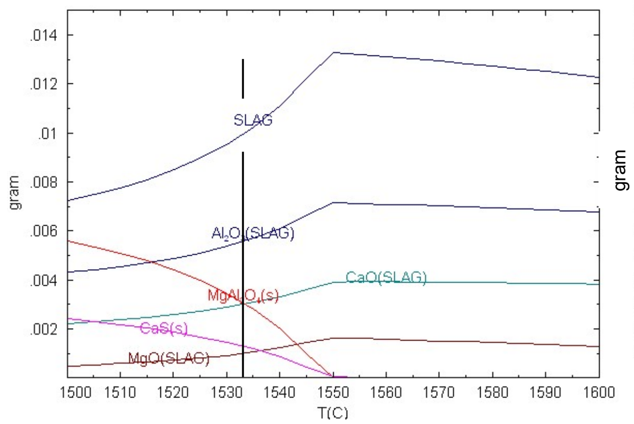




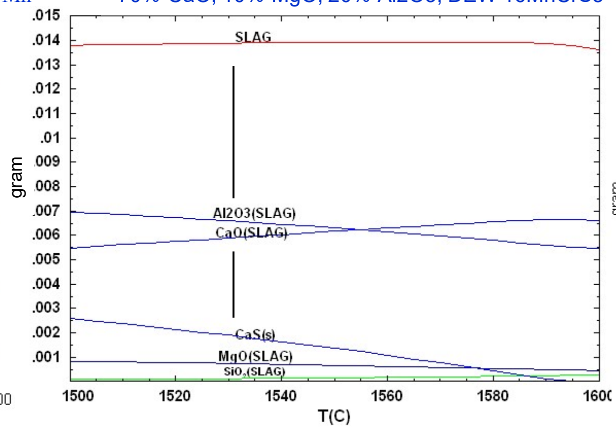


2) Increasing the basicity of tundish slag leads to improved capacity to absorb inclusions compared with standard practice → slag compositions with higher basicity were proposed for industrial trials

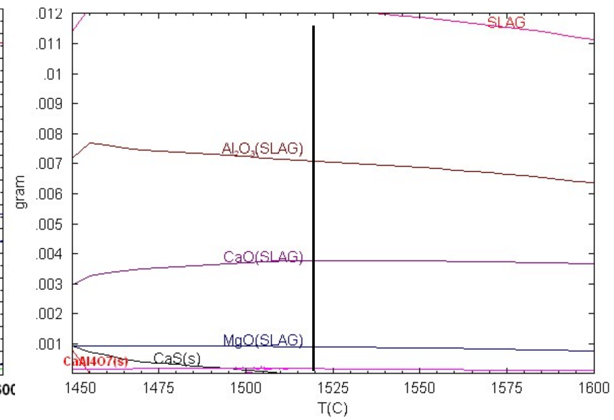
40%-CaO, 20%-MgO, 25%-SiO2, 5%-Al2O3, TATA C/Mn



70%-CaO, 10%-MgO, 20%-Al2O3, DEW 16MnCrS5

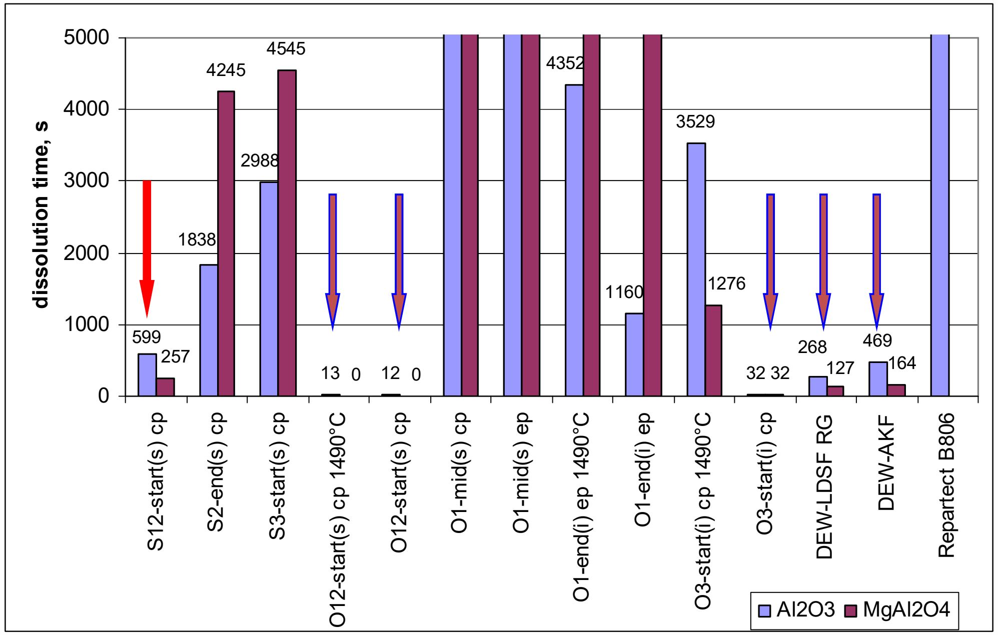


40%-CaO, 10%-MgO, 20%-SiO2, 30%-Al2O3-30, OVAKO SEA1050



Main Results - Dissolution Kinetics of Non-Metallic Inclusions

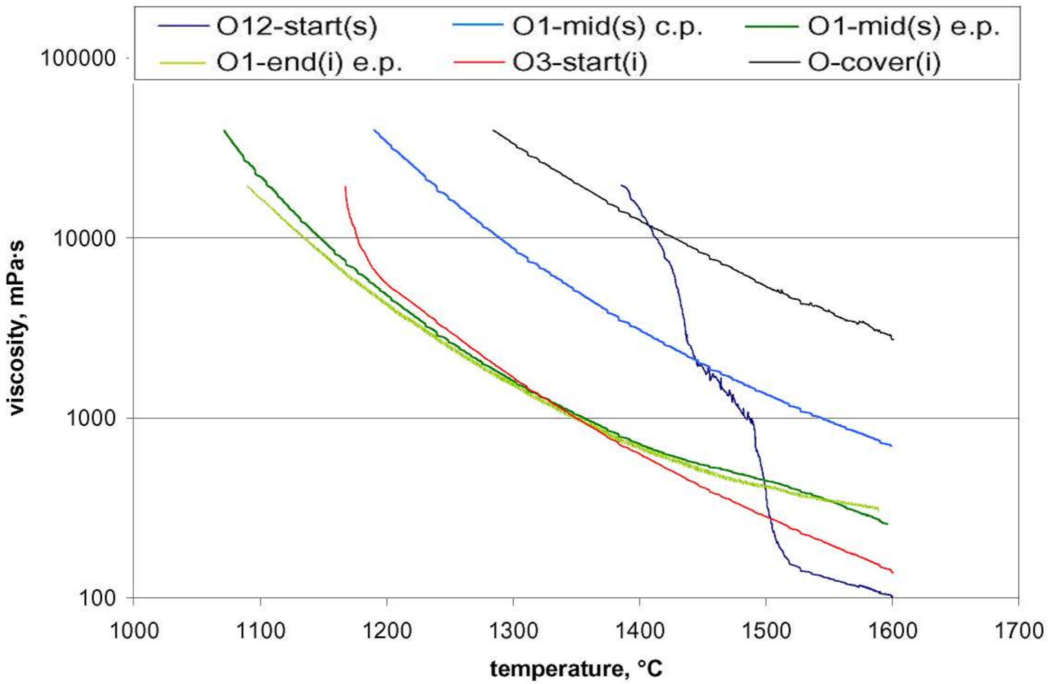
In general, dissolution of inclusions is much slower in acid slags than in basic slags



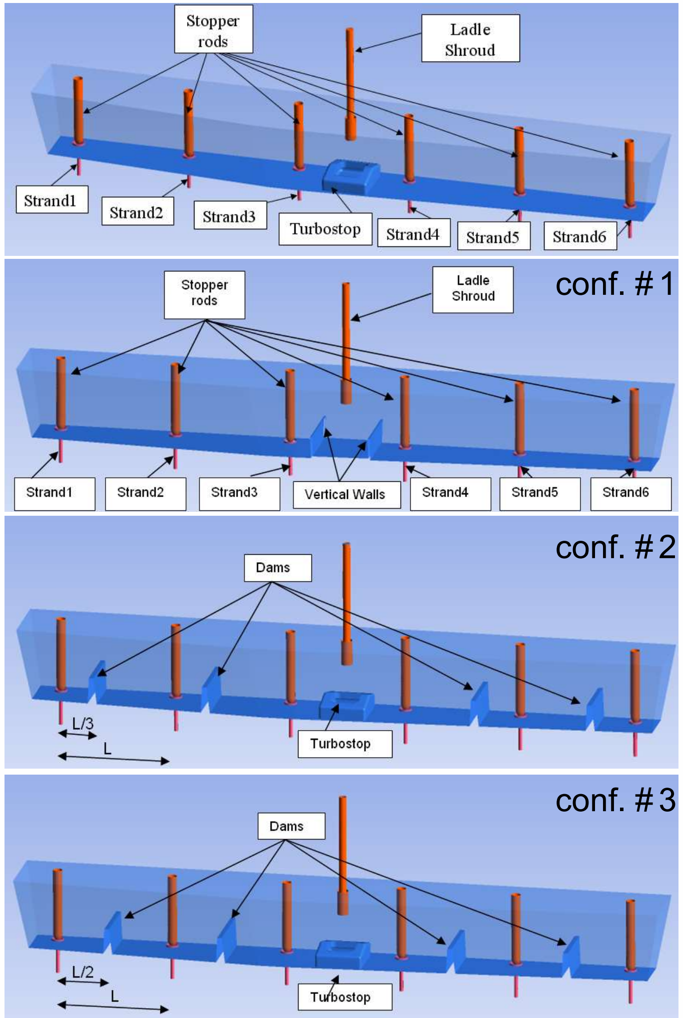
code	CaO	MgO	SiO_2	Al_2O_3	$\frac{\%CaO+\%MgO}{\%SiO_2}$
S12-start cp	21.9	12.8	46.6	19.2	0.74
S2-end cp	17.8	16.5	42.0	21.8	0.82
S3-start cp	17.9	10.9	40.9	15.8	0.70
O12-start cp	44.8	12.6	22.3	19.1	2.57
O1-mid cp	15.7	7.5	41.8	30.5	0.56
O1-mid ep	21.3	12.7	37.8	24.4	0.90
O1-end ep	17.5	11.8	38.3	21.7	0.77
O3-start cp	46.8	-	0.5	43.5	93.6
DEW-LDSF	49.6	0.7	3.3	42.6	15.24
DEW-AKF	48.0	0.8	-	51.3	
Rep.-B806	42.9	9.6	25.0	19.9	2.1

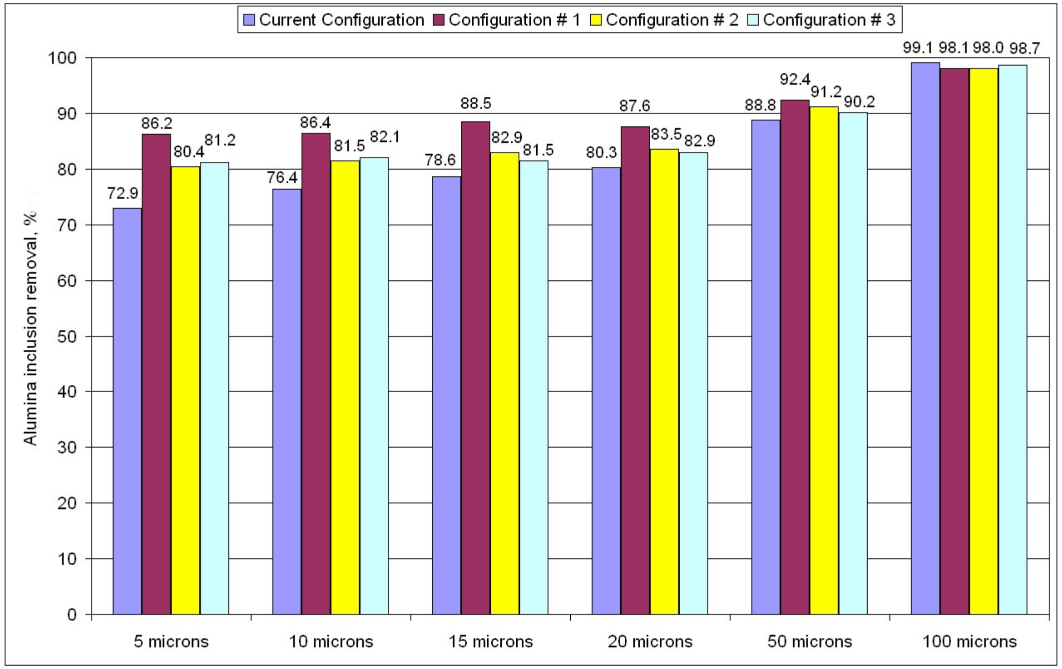
Main Results - Dissolution Kinetics of Non-Metallic Inclusions

Slag viscosity was found to be important for dissolution of inclusions in tundish slag



Main Results – Tundish Design Optimisation – Optimal Flow Pattern for Inclusion Removal



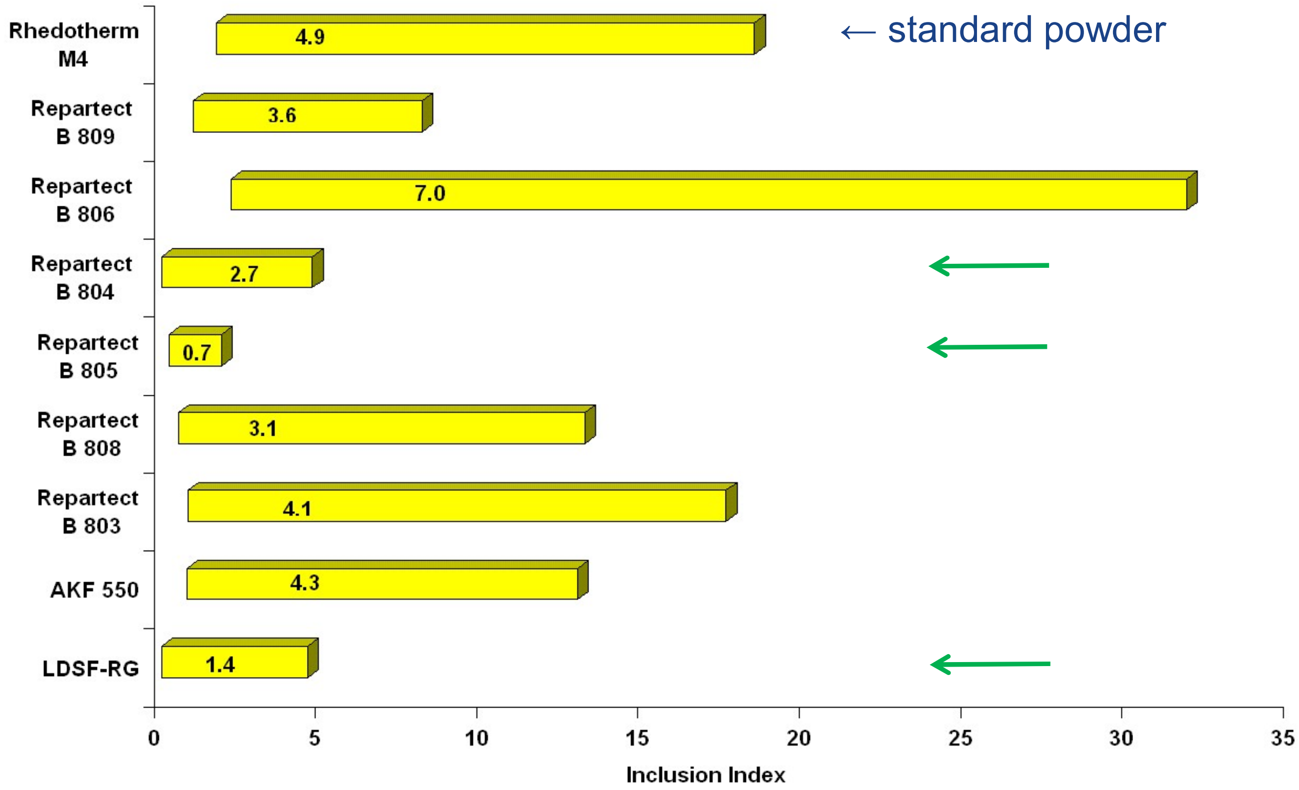


- Best removal rates were obtained with configuration # 1
- However no improvement in steel cleanness was observed in industrial trials at Sidenor compared to normal practice

Main Results - Dissolution kinetics of non-metallic inclusions

Experimental tests with the new proposed tundish powders showed improvement in steel cleanness compared with standard practice

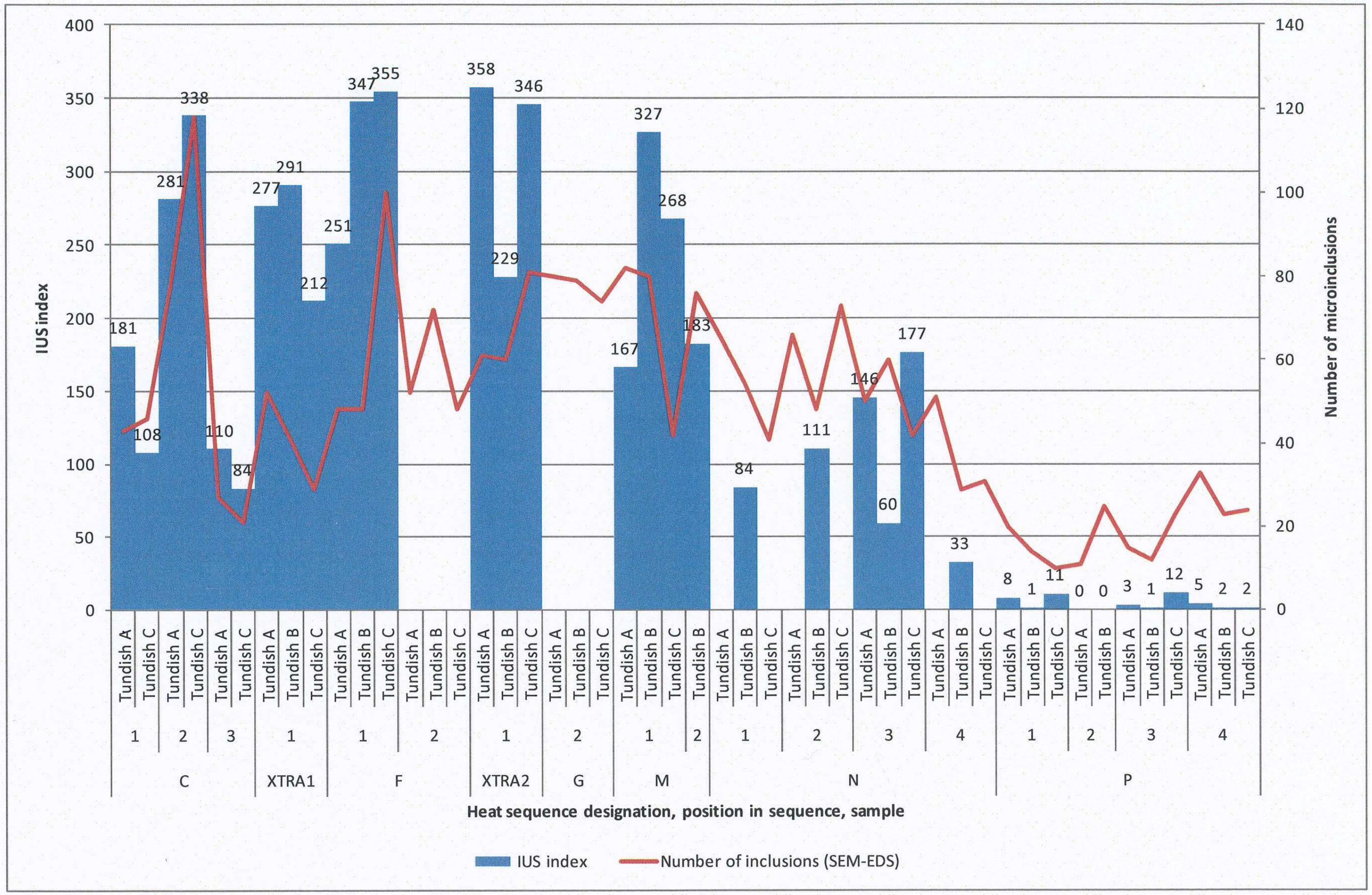
Example - Results of ultrasonic tests using different covering agents at DEW



bar = minimum-maximum range
number = average

Main Results – Industrial Trials

Example - Influence of new tundish practice (P1-P4) on steel cleanliness at Ovako.



Main Results – Industrial Trials

Example - Influence of new tundish cover practices on the casting parameters at Sidenor

	Standard Powder	NEW Powder
Sequenciability	✓	✗
Castability	✓	✓
Consumption	✗	✓
Stopper rods' jamming	✓	✗
Attack to the tundish refractory	✓	✓
Attack to the isostatic refractory	✓	✗
Cleanness (inclusion removal)	✓	✓
Cleanness (steel-slag interaction)	✗	✓

✓= positive
✗ = negative

Main Results – Industrial Implementation

- *At Ovako Imatra, due to good results with using the new powder, the old tundish powder practice was abandoned and a new basic powder was adopted into regular use*
- *At Sidenor, new tundish cover is used for heats with special cleanness requirements. However, sequence length is limited to three heats due to excessive erosion of the isostatic refractory pieces and hardening of the slag cover*
- *At DEW, good results with the proposed new cover powders (Repartect B804, B805 and LDSF-RG) requires verification in large scale production trials. A decision on whether to implement the new cover powders for standard tundish practice will be made on the basis of these large scale production trial results*
- *At Tata Steel, two new powders have been tested with good results. However the new powders will not be industrially implemented without further testing*

Summary

‘Optimisation and evaluation of different secondary steelmaking routes to achieve high quality strip steel’

- *Slag metallurgy and Ca treatment practices for strip grades have been developed and assessed on an industrial scale*

‘Active Tundish Metallurgy (AcTuM)’

- *Experimental tests at steel plants with new tundish powders showed improvement in steel cleanness compared with standard practice*

- *New tundish practices developed in this project have been successfully implemented at two of the partners’ works (Sidenor and Ovako)*

Thank you for your attention