Process optimization strategies for crack reduction

Edoardo D'Amanzo – Rina Consulting ✉ *edoardo.damanzo@curtisoftware.com*
Michele De Santis - Rina Consulting ✉ *michele.desantis_csm@rina.org*
Riccardo Tonelli – Rina Consulting ✉ *riccardo.tonelli@rina.org*

Research Fund for Coal & Steel

Process optimization

What means Process Optimization?

"definition of strategies such as tailoring operating practices and actions aimed to reduce the occurrence of defects in the final product, without detrimental impacts on productivity and safety conditions"

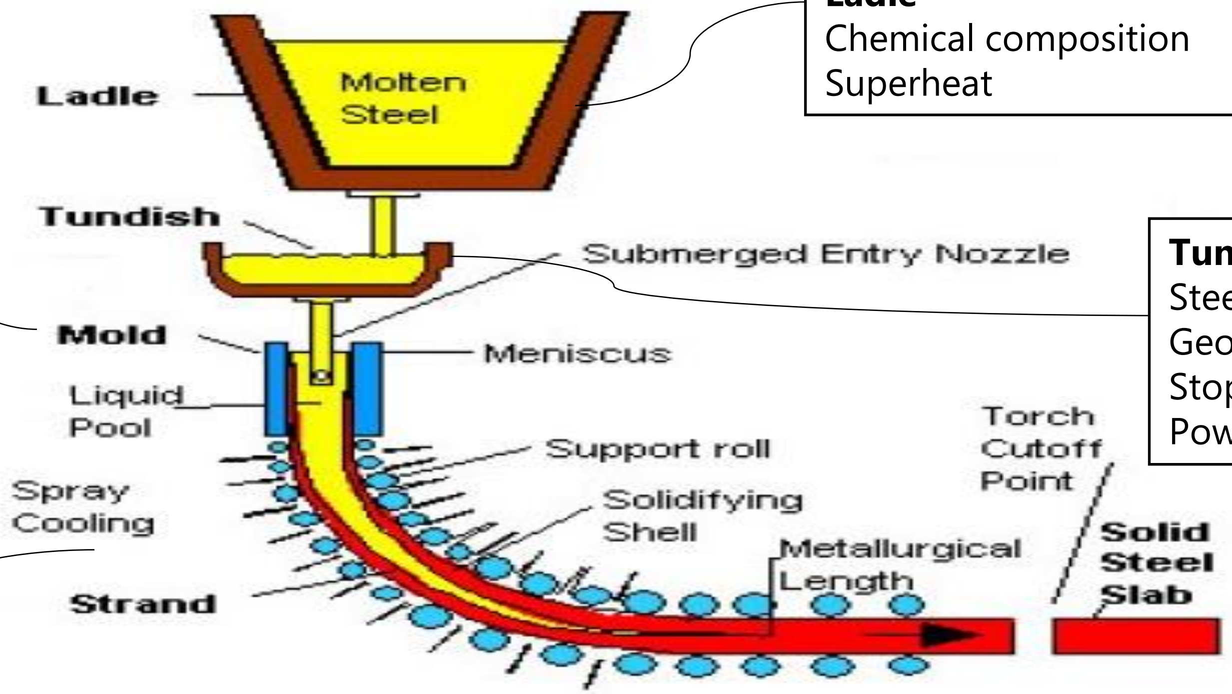
Process optimization

Process parameters

Many parameters can influence the occurrence of defects in CC.

Mould
Heat flux, water ΔT
Casting speed
Mould oscillation
Mould taper
Powder properties
SEN design
Level control
Electric Mould Stirring (EMS)

Ladle
Chemical composition
Superheat



Tundish
Steel protection
Geometry (dams, baffles)
Stopper Ar flowrate
Powder selection

Secondary cooling
Design (ex. nozzle position, distance, size, etc)
Water flowrate distribution
T trend along the strand

Process optimization

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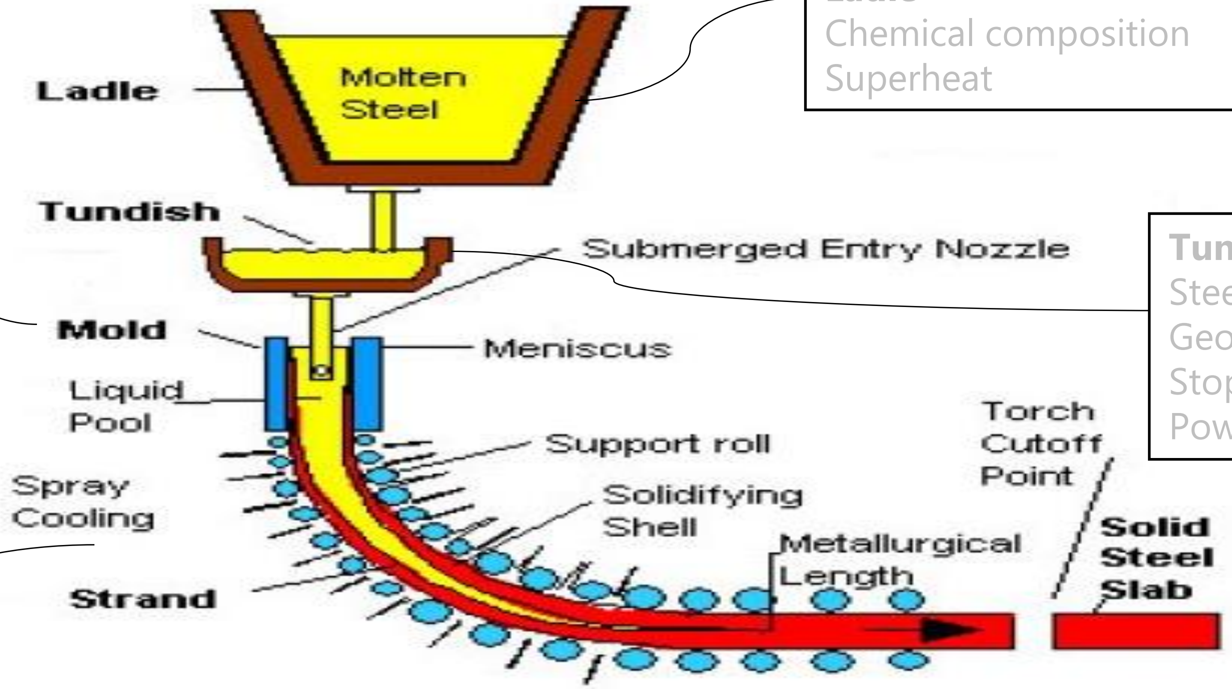

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The quality of slab/billet is strongly affected by several parameters, often interconnected each other

Process optimization

EU research

RFCS projects contribute to evaluate a wide range of interesting solutions.

VALCRA proposes a **deep analysis of RFCS projects**. It emerged **4 main sub-topics** concerning **process optimization** in CC (see D2.3 on VALCRA website):

Layout design	Modification to the caster define to reduce cracks formation
Operating conditions	Definition of operating windows to reduce cracks occurrence. Definition of rules for downgrading due to potential crack generation
Improved steel compositions	Optimization of steel chemical composition for improving castability and to reduce defect occurrence
Injection techniques	Identification of specific techniques for inoculant addition to liquid steel to modify solidification

First milestone of VALCRA project is the publishing of D3.1.
The main results of process optimization are highlighted.

Process optimization

RFCS concerning process optimization

Title	Acronym	Relevant sub-topics
Castability & surface quality of steels microalloyed with Ti or TiNb in continuous casting of slabs, thin slabs and beam blanks	-	Improved steel compositions
Improvement, control & prediction of cast & rolled products through development & application of novel engineering monitoring techniques.	CASTDESMON	Operating conditions
Enhanced as-cast product quality by optimised mould taper design.	SOLIMOULD	Layout design
Optimising slag film properties and determination of operational windows for lubrication, mould heat transfer and shell formation.	SLAGFILMOWL	Operating conditions
Precipitation behaviour of microalloyed steels during solidification and cooling.	PRECIPITATION	Operating conditions/Improved steel compositions
Grain size control in steel by means of dispersed non metallic inclusions	GRAINCONT	Injection techniques
Integrated models for defect free casting.	DEFFREE	Operating conditions
Intercolumnar cracking and its relationship to chemistry and applied strain.	ICCRACK	Operating conditions
Development of a toolbox for direct defect prediction and reduction through the characterisation of the meniscus slag bed behaviour and initial shell solidification in CC.	DIRECT DEFECT TOOLBOX-DDT	Layout design
Influence of composition and continuous casting parameters on the precipitation of microalloyed particles of B microalloyed steel grades and Mn alloyed steel grades.	PMAP	Operating conditions
Investigation of innovative methods for solidification control of liquid steel in the mould.	INNOSOLID	Layout design
Development of an integrative plant, process and quality supervisory system at CC by the intelligent combination of sensors, data analysis and decision support techniques.	SUPSYSCC	Operating conditions
Control of the dendritic structure of the initial frozen shell in continuous casting	-	Layout design
Determination of high temperature surface crack formation criteria in continuous casting and thin slab casting	-	Operating conditions

Process Optimization

Some examples

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Variation of mould geometry to prevent detachment of solidifying shell

Process Optimization

Some examples

Evaluation of Nb and Ti precipitation in microalloyed steels

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Improvement, control & prediction of cast & rolled products through development & application of novel engineering ... monitoring	...MON	Operating conditions
Enhanced as-cast product quality ...	...LD	Layout design
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Ti-Ce and Ti-Zr in Fe-Cr 20%. →
ZrN precipitates and acts as nucleation site for ferrite with grain size refinement

Process Optimization

Follows some detailed description of how optimization was performed in some RFCS projects

The projects reported in the following slides are selected just to cover different topics concerning process optimization.

Moreover, they do not report all the arguments developed in the entire project.

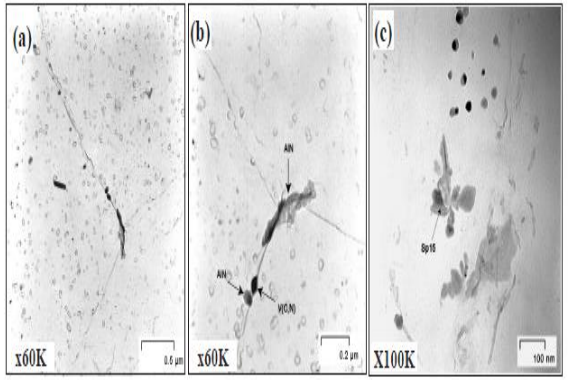
PROCESS OPTIMIZATION

RFCS project : PRECIPITATION 1/2

Steelgrade: V-steel, peritectic, slab

Surface Transverse cracks due to:

- V(C,N) precipitates
- Globular Cr
- AlN along austenitic grains



V has the advantage of greater solubility in the austenite.
But V offers no effective resistance to austenite recrystallisation during hot rolling due to larger solubility of V(C,N).

Substitution of V with Nb.
The Nb(CN) precipitates much earlier in Nb steel than V(CN) in V steel. Consequently Nb impairs the austenite grain growth and this results in a smaller ferrite grain sizes and improved mechanical properties.

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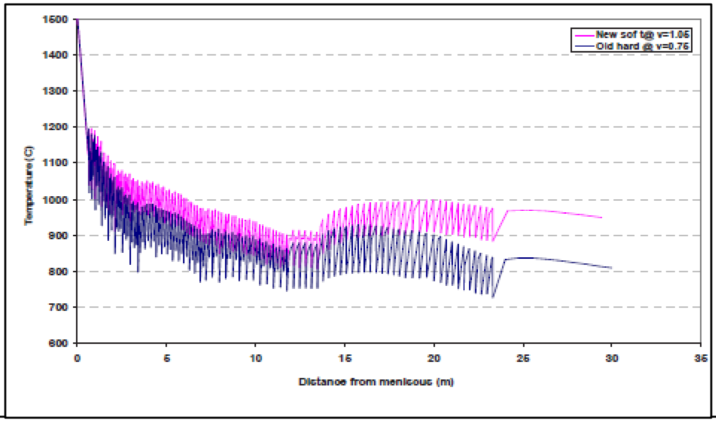


New secondary cooling pattern. T> 900°C

→

Reduction of more than 50% transverse cracking

PROCESS OPTIMIZATION

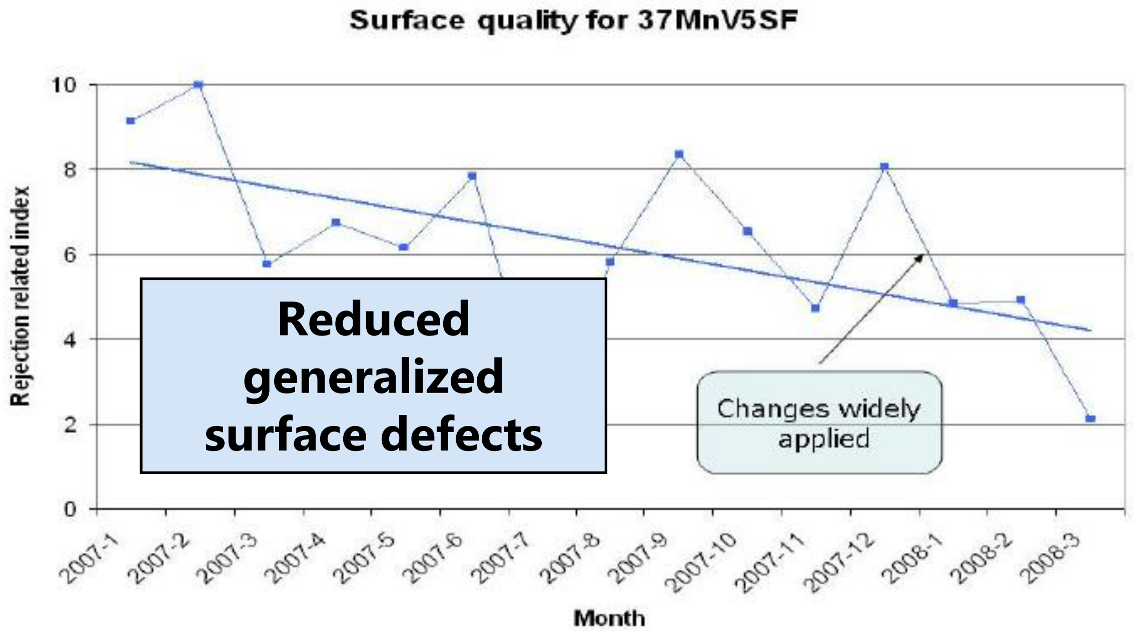
RFCS project : PRECIPITATION 2/2

Microalloyed Steelgrade: 37MnV5, billet

1st attempt
Substitution of V with Nb

→ ***Detrimental mechanical properties***

- **New secondary water-cooling curves** were generated; the same total amount of water is distributed with less water in the first zone. This results in more uniform cooling.
- **More vacuum time** is allocated during secondary metallurgy to improve castability.
- **A new mould powder** was introduced to minimize billet/mould friction and better initial solidification



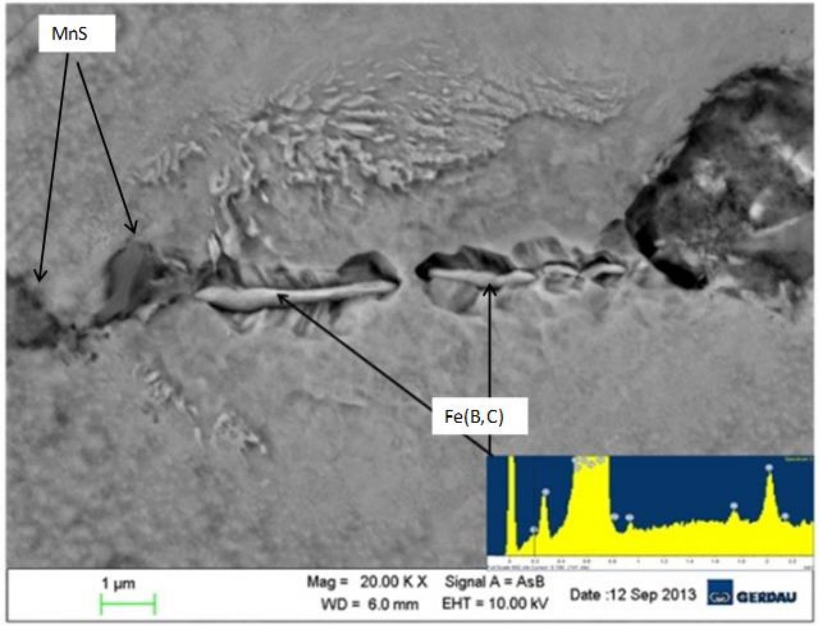
Process Optimization

RFCS project : PMAP

Steelgrade: 30MnCrB5E with B addition, billets

What we learnt:

- **B enriches in the interdendritic liquid** producing a **low melting** interdendritic **liquid** which enhances cracking, like the effect of sulphur for a low Mn/S ratio steel grade.
- **B impairs pro-eutectoid ferrite precipitation** at the austenite grain boundaries, and by this way **increases the internal strains** related to perlite transformation



For avoiding internal billet cracking in B steel grades the casting parameters which could produce strains in the solidifying shell have to be optimized.

Process Optimization

RFCS project : PMAP, SIDENOR VALCRA STUDIES

Steel grades with $(Mn/S) < (Mn/S)_{critic}$ or B steel grades

Cracking name	Mechanism producing cracking	Casting which should be optimized
Off-corner cracking	High billet/mould friction	Mould taper, mould wear
	Billet surface reheating inside the mould	Mould taper
	Bulging at mould exit	Zone 1 water cooling intensity
		Foot rolls adjustment
Off-corner reheating cracking	Billet surface reheating in the Zone 1-2 transition Nozzle clogging on secondary cooling zone	Adjust of water cooling Decrease distance between zones 1-2 Increase casting speed
Half-way cracking	Billet reheating between zones 2-3, end of secondary cooling	Correct design of secondary cooling Decrease distance between cooling zones, when it is not possible to increase casting speed
Mid-face transformations stress cracks	Stresses due to high billet cooling rate or a composition promoting fast Austenite/perlite transformation.	Slow billet cooling at cooling bed Avoid air draught at tertiary cooling

Process Optimization

RFCS project : SLAGFILMOWL

Steelgrade: duplex stainless steel

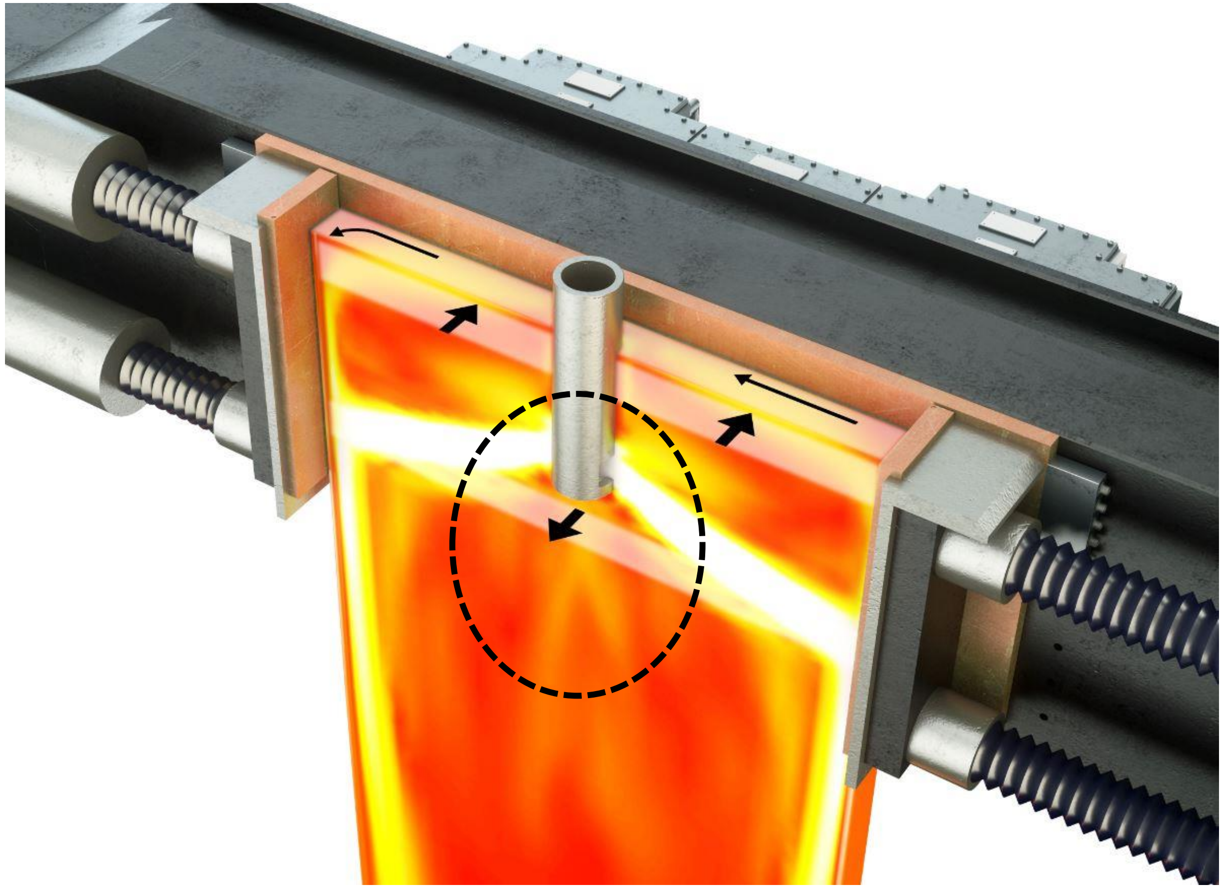
Deep longitudinal cracks

(on the loose side in the SEN region)

Process Optimization

RFCS project : SLAGFILMOWL

Steelgrade: duplex stainless steel



- In SEN region, the melt flow is very stagnant.
- This is mainly caused by low depth of molten slag in that area.
- Retarded shell formation on wide face leads to crack formation.
- New thermocouples on the mould faces and use of new solidification mathematical model, new solutions have been proposed and tested

Process Optimization

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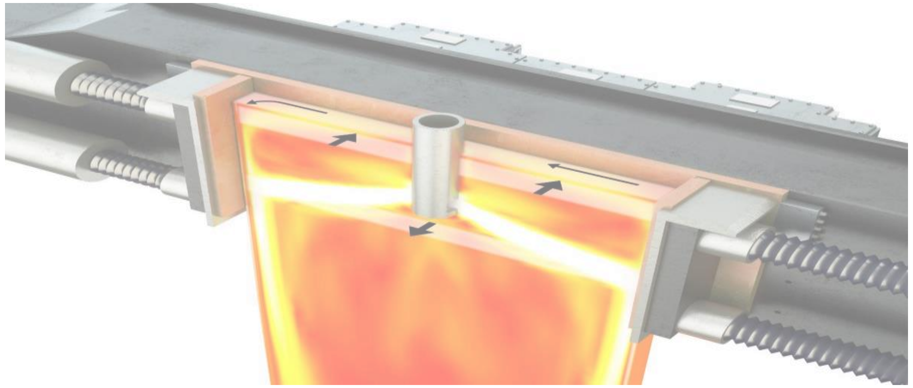

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Significant improvements were achieved by means:

- Application of new powder (reduced Na_2O and increase fluorine)
- Low heat flux for "soft cooling" that evens the shell formation reducing tensions in the shell
- Increase the superheat to give higher heat input in the SEN region

Improvements have been recorded also in terms of oscillation marks depth

Process Optimization

SUPSYSS

The project concerns the implementation of new rules for the downgrading of the final products and monitoring of production.

Detected defects:
- Marks in the slab surface
- Slivers due to mould powder, alumina or other non-metallic inclusions
- Blisters

Sensor systems related to:
- mould plate monitoring
- caster drive monitoring
- inspection of slab surface quality by conoscopic holography

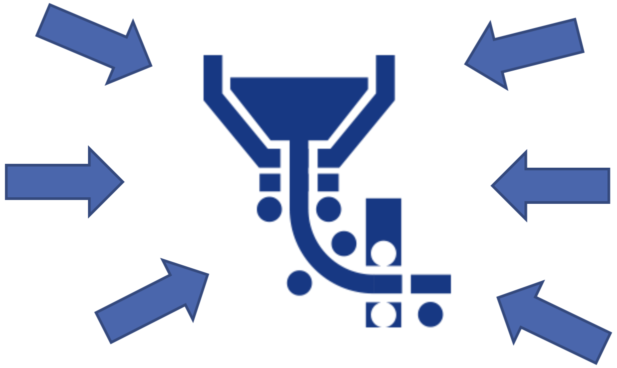
N°	EVENT	VARIABLE CONTROL	DEFECT
1	Al drop SM - tundish	Med(Al tot, Alsol) - AltotTD	Al2O3
2	Al drop during casting	Al tot(n-1) - Al tot(n)	Al2O3
3	No shroud LD-TD	PLC	Al2O3
4	Argon flow LD-TD	Argon flow	Al2O3
5	Ladle open with O2	PLC	Al2O3
6	High mould level variation	Level sensor	Inclusions / cracks
7	Very high mould level variation	Level sensor	Inclusions / cracks
8	Level control not automatic	PLC	Inclusions / cracks
9	Cleaning	PLC	Inclusions / cracks
10	Break out alarm	SAPSOL	Sticking

Example of events gathered in the continuous caster quality model (SUPSYSS, table 23)

Benefits
- No break-out and no defect crisis due to oscillation failures since alarm is active.
- On-line checking of the machine status, which is a very good complement to the periodic checking during the maintenance stops.

Process Optimization

Conclusions



- The optimization of continuous casting process involves *many variables:* **there is no a general recipe to optimize the production process**

- Many RFCS projects concern the study of microalloyed steels. Innovative countermeasures thanks to identification of new crack formation mechanisms have been detected.
- It is well known that solidification and cooling control (primary, secondary and tertiary) are fundamental to achieve proper product quality. In that frame, new solutions have been proposed, achieving optimal results in a more sustainable and economical way

- As reported in D2.3, most of technical solutions developed during various RFCS projects, have achieved a TRL 6/7 starting from a TRL 2/3. It means that **EU funded research is an important tool to improve industrial production quality**

Process Optimization

Future developments

Nevertheless the important results achieved in the last 25 years of EU research, **future developments** are always required:

- Improved caster design has been a subject of the present topic. Despite the **high potential** of the technology, **few solutions have been explored**. Other innovative layouts found issues related to their spread, probably since the **high cost of investment**.

- Modelling and reliable monitoring systems are fundamental to detect the optimum combination of variables. **New tools lead to new optimization strategies**

- RFCS projects lacks sometimes of a relevant study concerning environmental problems. **In the frame of EU climate targets 2030-2050, it shall be appropriate to deeper these aspects**

Thanks for the attention!

Stay informed

http://valcra.eu/

https://www.linkedin.com/company/european-continuous-casting-network

VALCRA linkedin group (linkedin.com/groups/13794289/)