The fundamentals of the crack formation: chemistry and physics

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European Commission

Research Fund for Coal & Steel

Introduction

After 60 years of continuous casting steel production, is cracking of CC semis still a quality problem?

The fundamentals of the crack formation.

Introduction

History of continuous casting at Sidenor

<table>
<tr><th>YEAR</th><th>CASTING SIZES (mm)</th><th>CASTING SPEED</th><th>STEEL GRADES</th><th>OBSERVATIONS</th></tr>
<tr><td>< 1985</td><td>125
145</td><td rowspan="4">Continuous increase</td><td rowspan="4">More difficult to cast
Microalloyed steel grades: Al, N, V, B, Nb
Microalloyed + S.</td><td rowspan="4">Much knowledge developed
New technologies: EMS, mould and oscillation, secondary cooling…
Advances on online control…
However:
The productivity requirements,
More difficult to cast steel grades
Higher quality requirements.
CRACKING REMAINS A BIG PROBLEM</td></tr>
<tr><td>1985 – 2000</td><td>145
170</td></tr>
<tr><td>2000 – 2018</td><td>155
185</td></tr>
<tr><td>>2018</td><td>155
185
240</td></tr>
<tr><td>BLOOM > 2012</td><td>350x470</td><td></td><td></td><td></td></tr>
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The fundamentals of the crack formation.

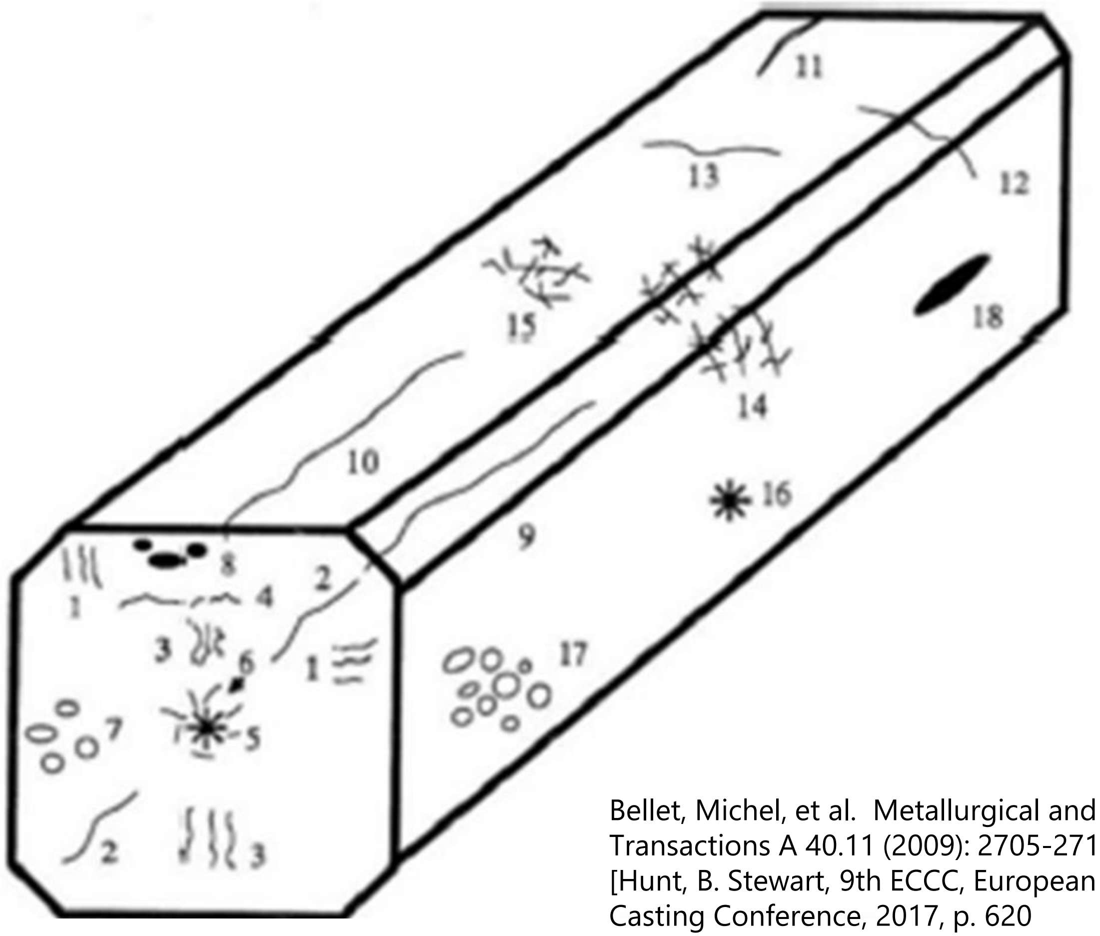
Introduction

Internal defects:

1. Off-corner cracks
2. Corner cracks
3. Half-Way Crack
4. Transversal cracks
5. Star-Crack
6. Central pipe
7. Pore, blown holes
8. Powder entrapment

Surface defects:

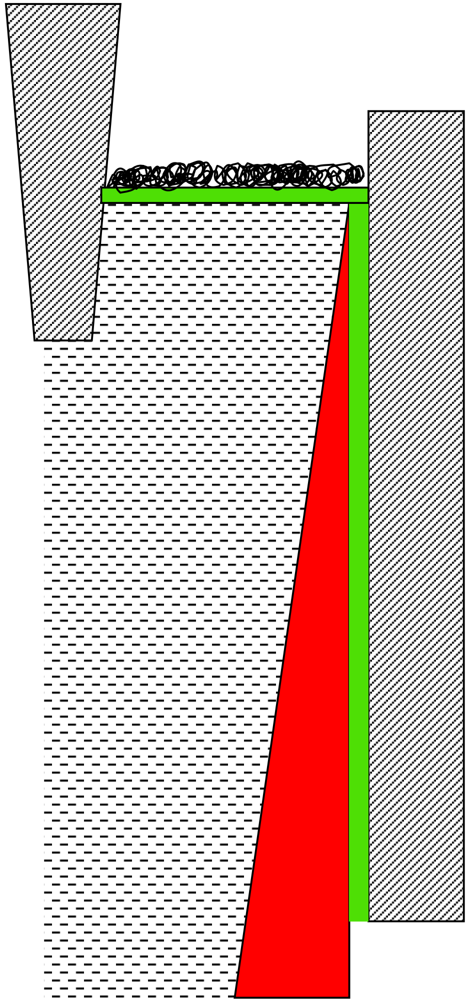
9. Corner cracks
10. Longitudinal cracks
11. Thermal/transformation longitudinal cracks
12. Corner transversal cracks
13. Face transversal cracks
14. Intergranular cracks (corner)
15. Intergranular cracks (face)
16. Surface star cracks Start cracks
17. Pores, blow holes
18. Powder entrapment

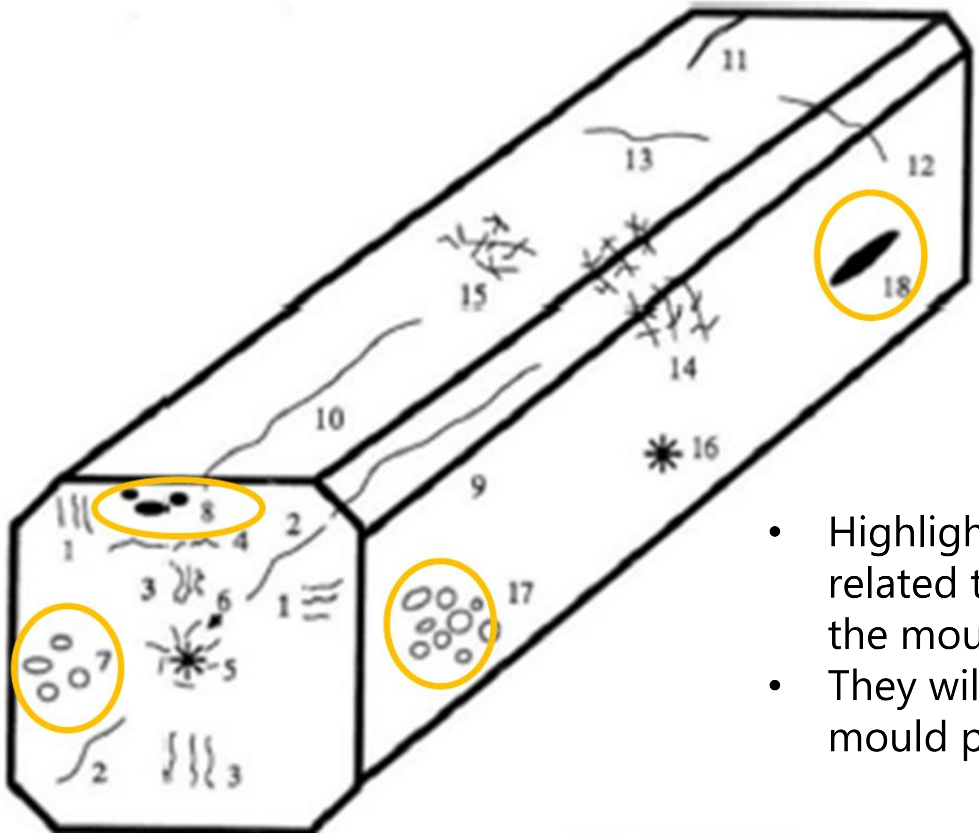


Bellet, Michel, et al. Metallurgical and Materials Transactions A 40.11 (2009): 2705-2717.
[Hunt, B. Stewart, 9th ECCC, European Continuous Casting Conference, 2017, p. 620

The fundamentals of the crack formation.

Introduction





- Highlighted defects are related to solidification in the mould upper part.
- They will be treated in the mould powder session

Bellet, Michel, et al. Metallurgical and Materials Transactions A 40.11 (2009): 2705-2717.
[Hunt, B. Stewart, 9th ECCC, European Continuous Casting Conference, 2017, p. 620

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Introduction

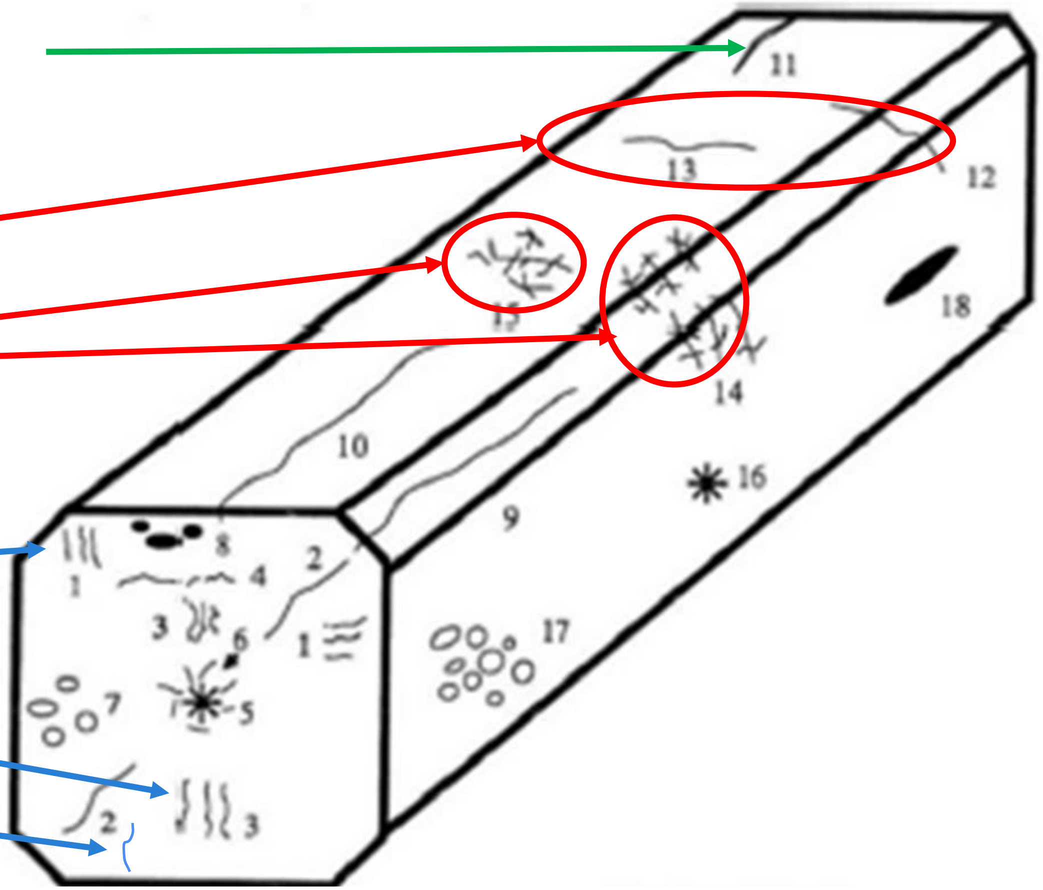
Thermal/Transformation Stress Cracks

Surface cracks:

- Transversal cracks
- Intergranular cracks

Internal segregation cracks:

- Off-corner cracks
- Half-way cracks
- Near corner cracks



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5/03/2020

Worshop on microalloyed steels and cracks in continuously cast billets

www.valcra.eu

www.sidenor.com

AGENDA

9:15 -9:30 h Introduction. Classification of cracks in continuously cast billets. Objectives of the European dissemination Project VALCRA.

9:30 -10:45 h Internal segregation cracks (Ghost lines)

- Formation mechanism. Influence of S, Mn and Boron.
- Influence of casting parameters.

10.45 - 11.00 h Coffee break

11:00 – 12:15 h Surface cracks in billets

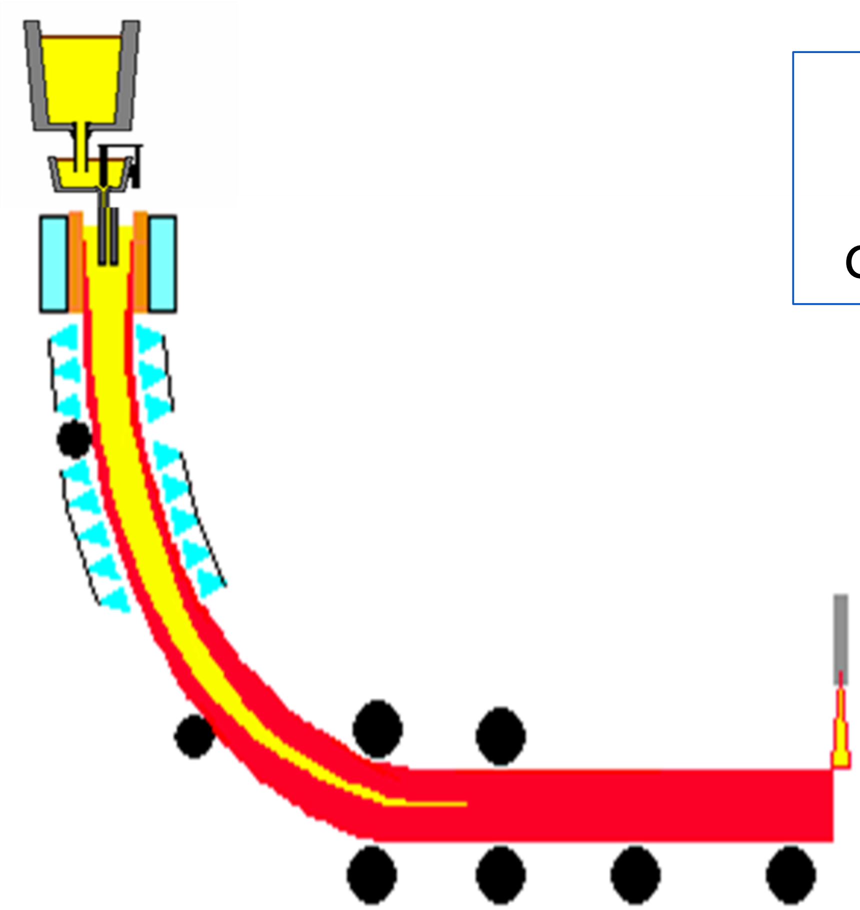
- Influence of microalloyed elements on hot ductility: Ti, Al, B, Nb, V, N.
- Influence of casting conditions

12:15 - 12.45 h Thermal/transformation cracking in the tertiary cooling.

12:45 - 13.00 h Final conclusions

The fundamentals of the crack formation.

Introduction



Susceptible chemical compositions

Stress at the solid shell

Internal Segregation cracks,
Surface crack,
Thermal/Transformation

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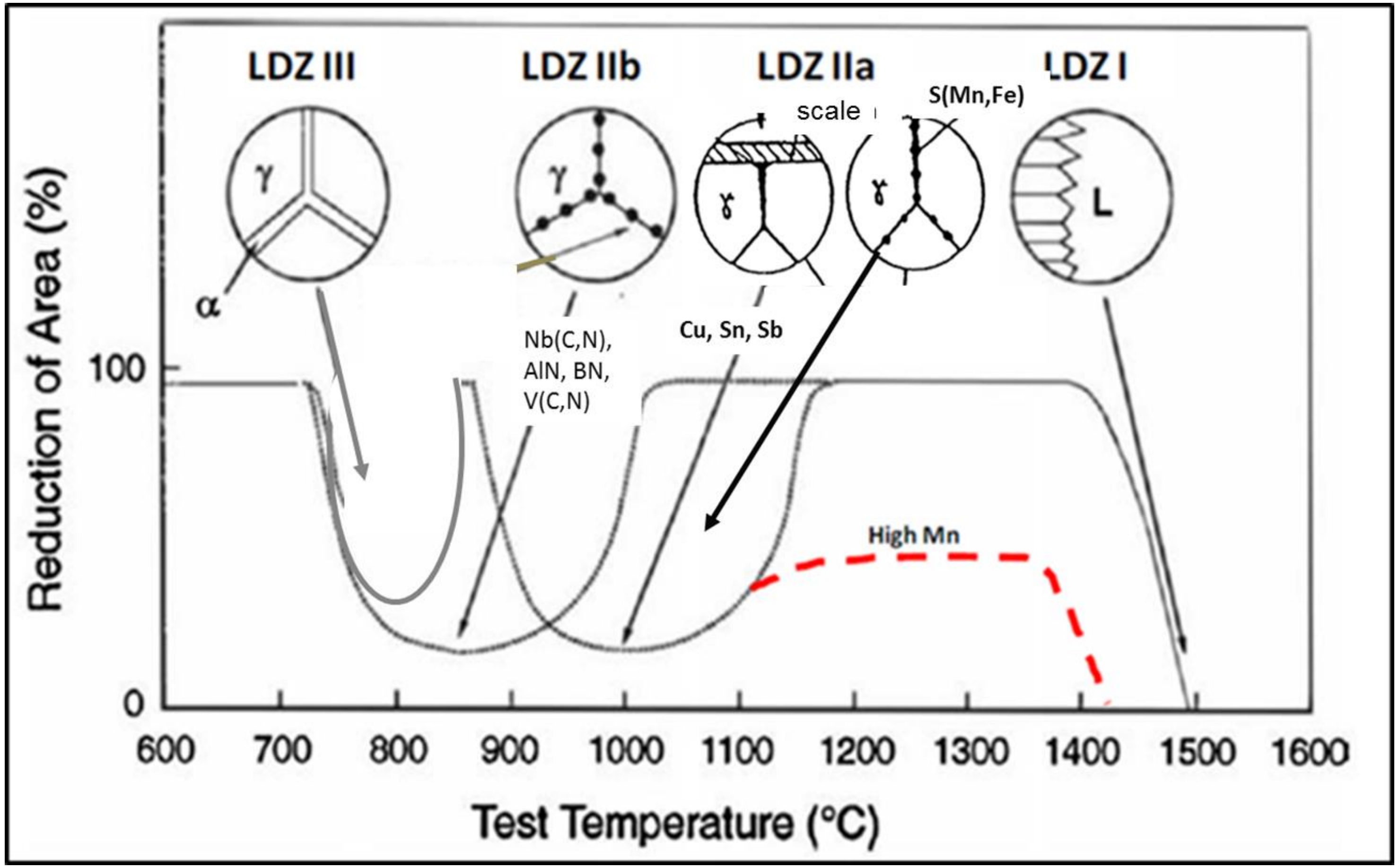
1. Introduction

Chemical composition

High temperature ductility troughs during solidification and cooling of the CC billet.

LDZ I: Internal segregation cracking.
LDZ II and LDZIII: Surface Cracks and Thermal/transformation cracks



D. Crowther: Mater. Sci. Technol., 1986, vol. 2 (7), pp. 1099–105.

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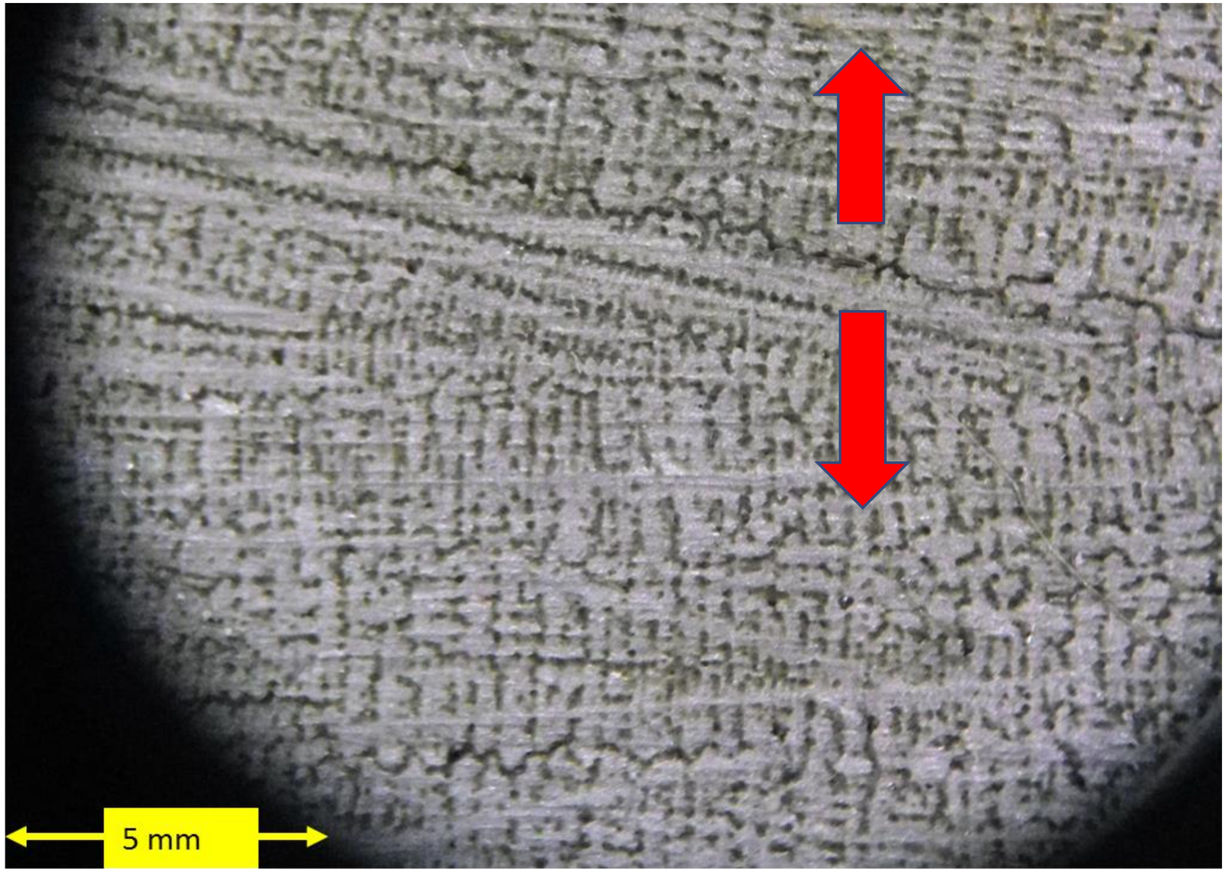
2. Internal segregation cracks

1. Segregation cracking formation mechanism
2. Influence of composition on segregation cracking: Sulfur, Boron
3. Classification of cracks: Half-way cracking, Off-corner cracking, Near corner cracking.

2. Internal segregation cracks

18NiCrMo5E 185 mm billet. Hot acid eching.
Crystal columnar growth area. Distance to billet surface: 60 mm.



Strain to produce cracking: >0.5%

Composition susceptible to segregation cracking: low melting interdendritic liquid.

Chemical elements: C, S, B, Nb.
$Mn/S < (Mn/S)c$
$(Mn/S)c = 1{,}345 \cdot S^{(-0{,}7934)}$

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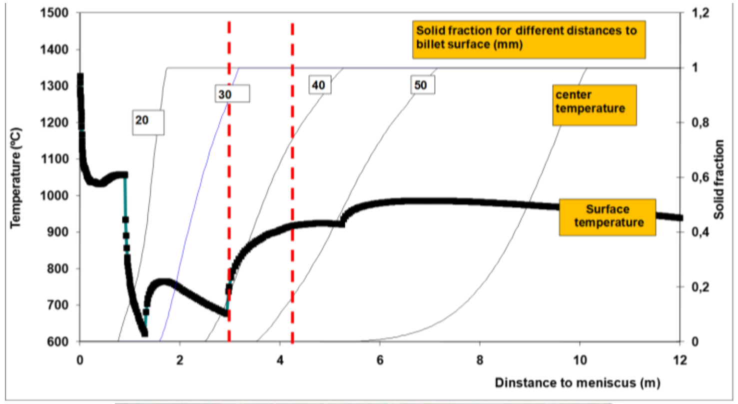
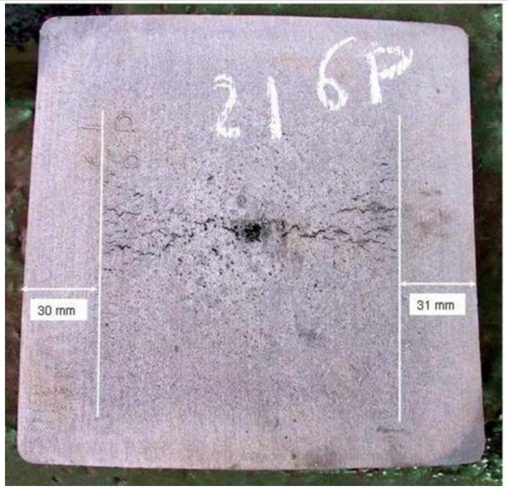
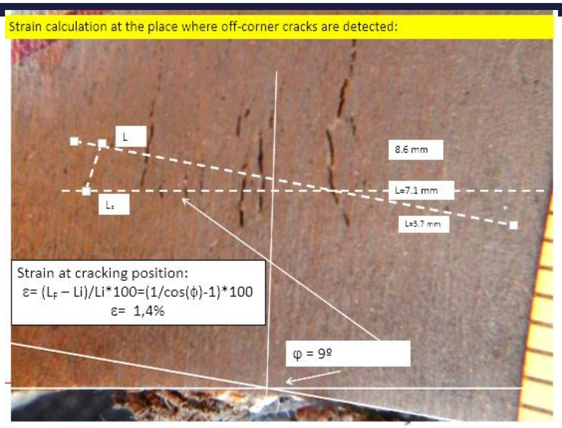
2. Internal segregation cracks

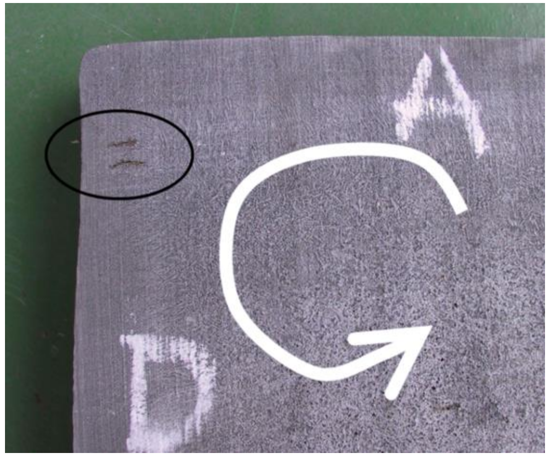




Half-way cracks

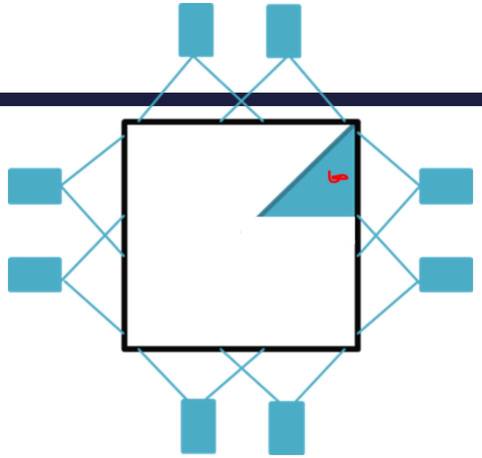
Secondary cooling

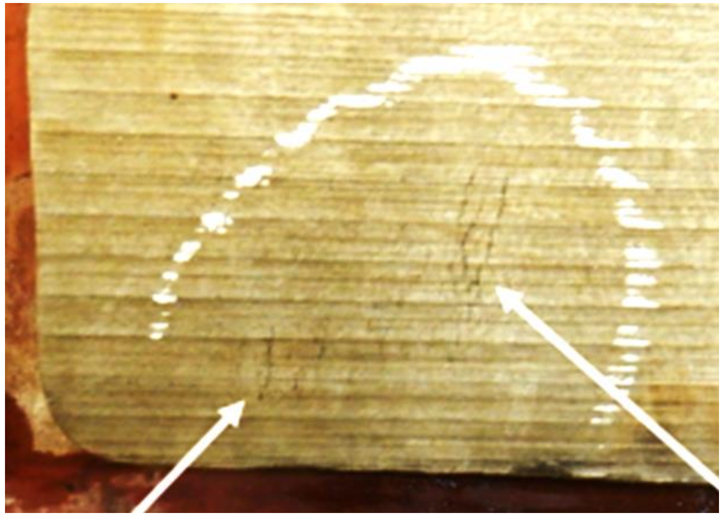




Off-corner cracks

Mould lower part or exit of the mold





Near corner cracks

Foot rolls or Zone 2.

Two nozzles by billet face.

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3. Surface cracks on billets: intergranular and transversal cracking

1. **Introduction: stresses at the surface of the CCM**
2. **Influence of the γ/α transformation and of the Austenitic Grain Size on cracking**
3. **Influence of the microalloying elements on hot ductility.**
4. **Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.**

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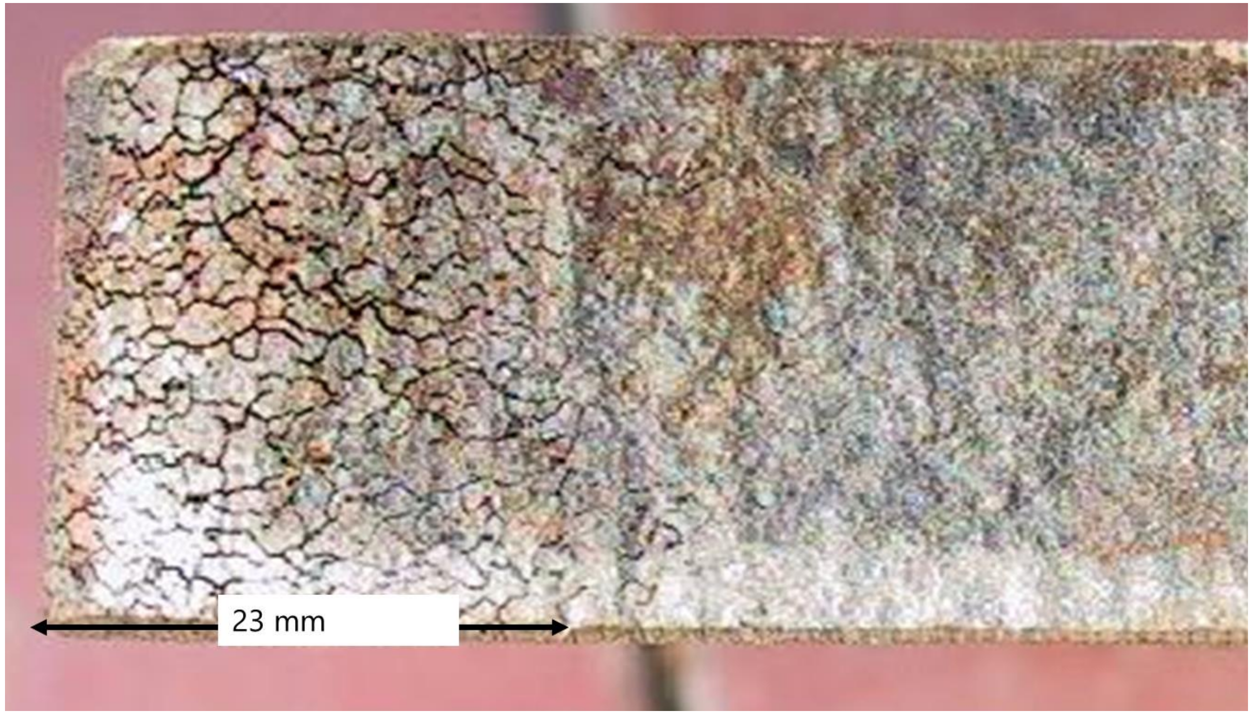
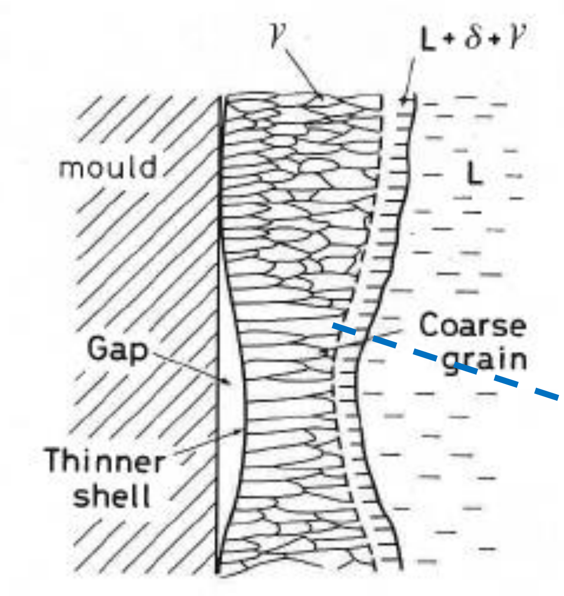
3. Surface cracks on billets: intergranular and transversal cracking

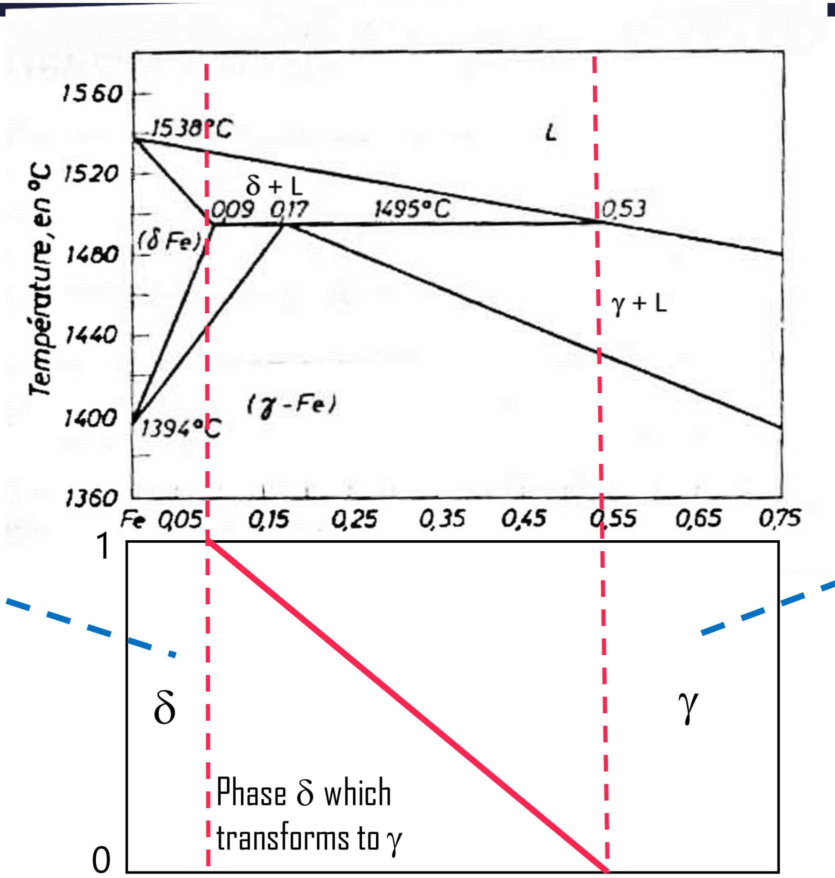
Billet corner of sample S3B4, 19MnNbV5C steel grade.
Hot acid etching

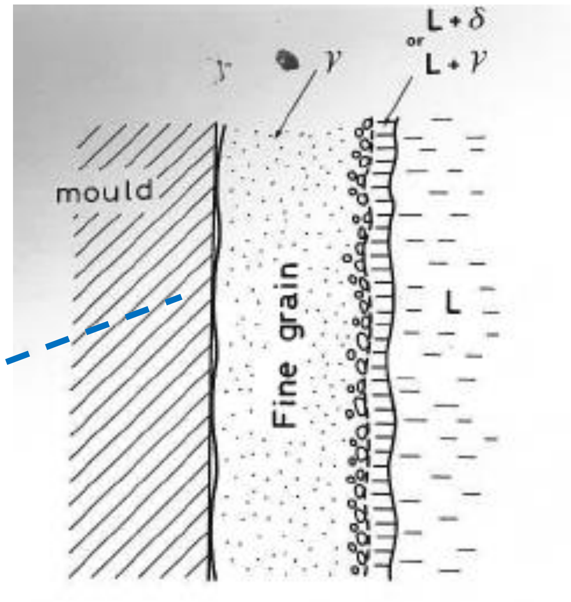


2. Surface cracks on billets: intergranular and transversal cracking

Steel composition influence on austenitic grain size:







Y. Mahera et al. Mat Sci. and Tech. 1990, V.6, 793-806

Carbon equivalent for peritectic reaction

Cp = C +0,02*Mn+0,04*Ni-0,1*Si-0,04*Cr-0,1*Mo-0,7*S

M. Wolf. 1st ECCC Florence, 1991, V. 2, 489-499

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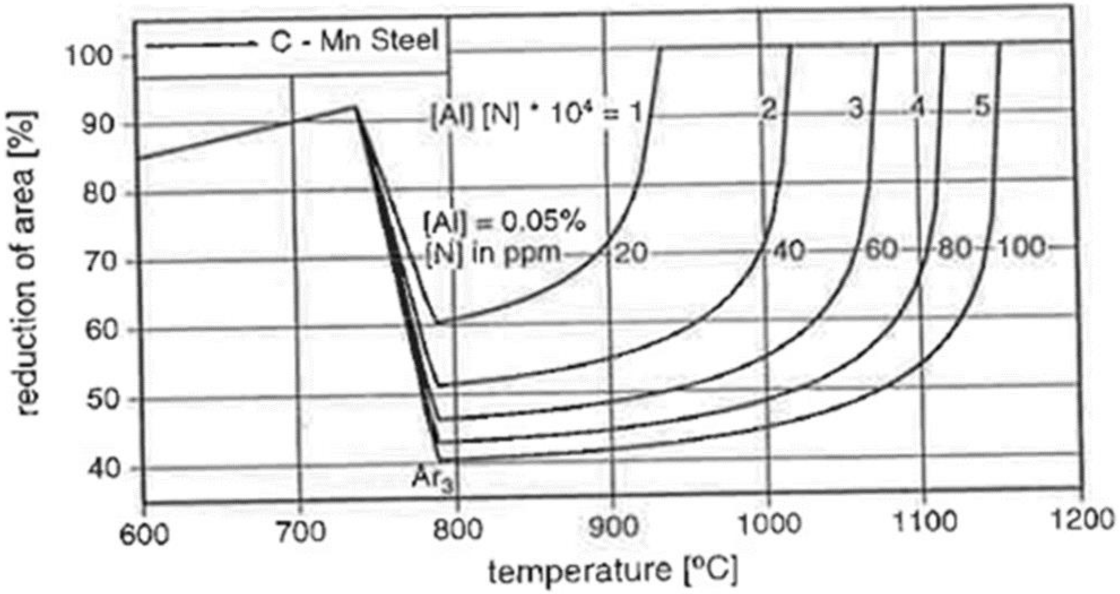
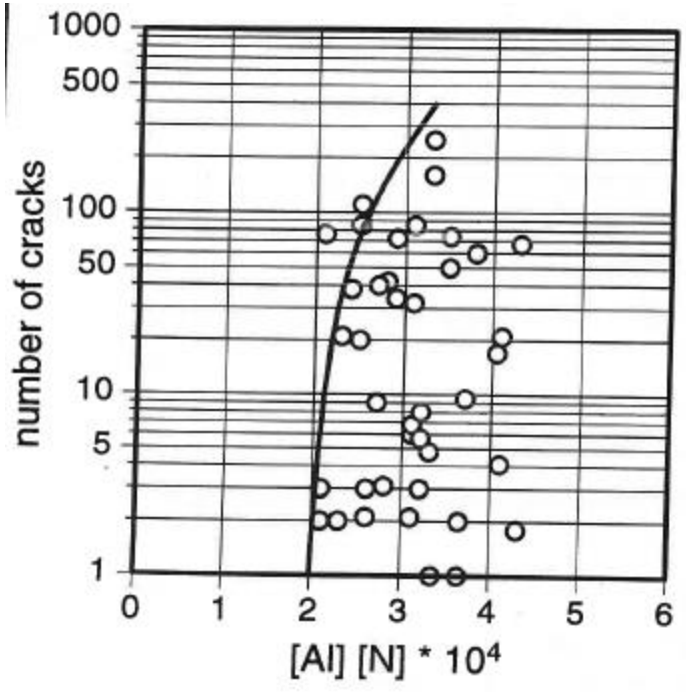
3. Influence of the microalloying elements on hot ductility.

Influence of the AlN





- Ductility curves of a C-Mn steel with a 0.050% of aluminum in composition and different N contents.
- As the product Al*N increases, the ductility trough widens, this being related to AlN precipitating at higher temperatures.

Relationship between crack index and the N*Al product.

Dillinger Hüttenwerke “Crack prevention in Continuous casting” 7210-CA/833, 1996

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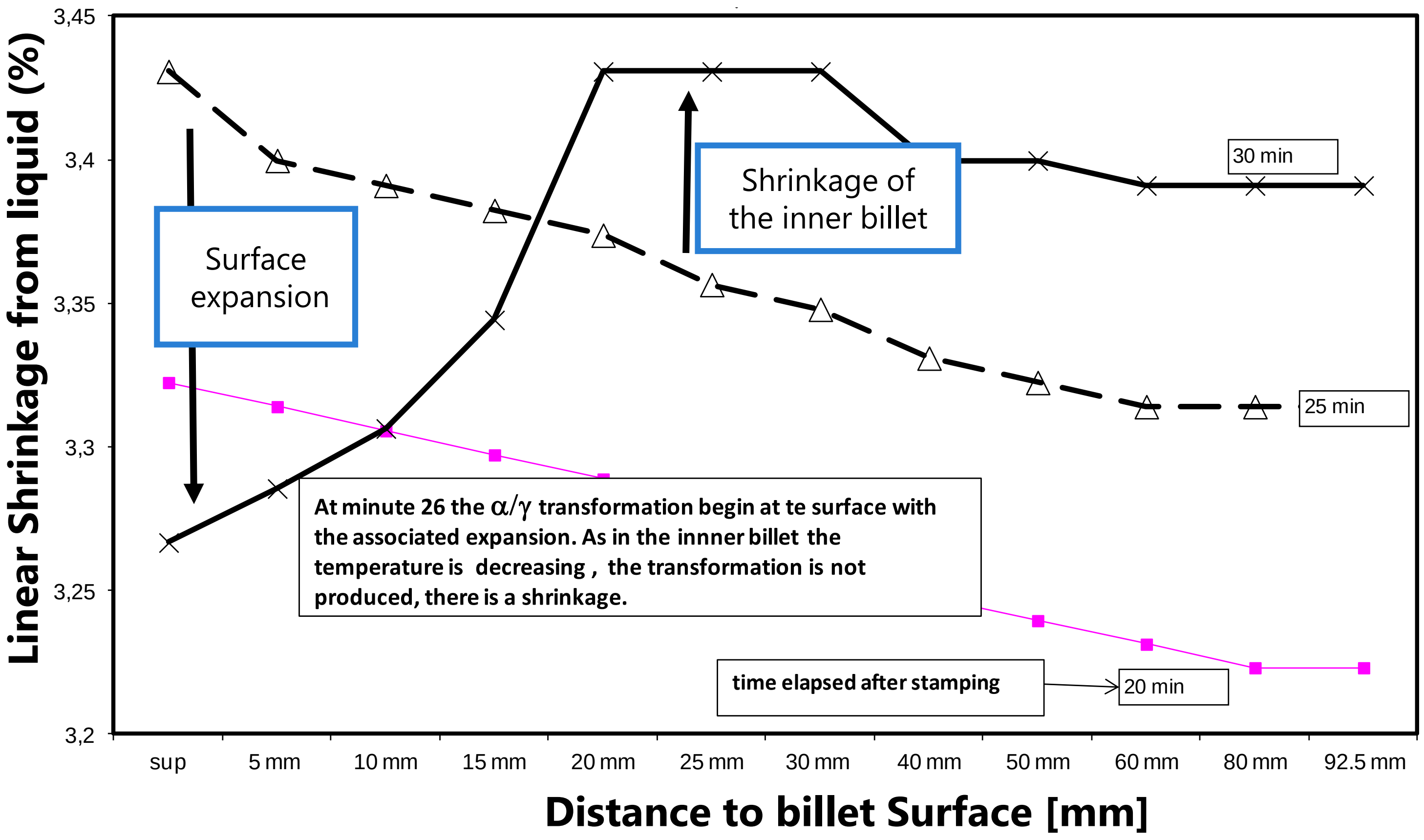
4. Transformation Stress Cracks at the tertiary cooling

1. **Characterization of Thermal/transformation Stress Cracks on billets (TSC)**
2. **Study of the Thermal and Metallurgical mechanisms producing TSC**
3. **TSC Susceptible Compositions**
4. **CC Tertiary Cooling Characterization**

4. Transformation Stress Cracks at the tertiary cooling

Transformation influence: Volume changes

- 26 minutes after the stamping, the volume expansion related with the γ/α transformation changes the shrinkage pattern.
- Nevertheless, even for a 30 minutes time, untransformed inner billet continues to shrinks due to decreasing temperatures.



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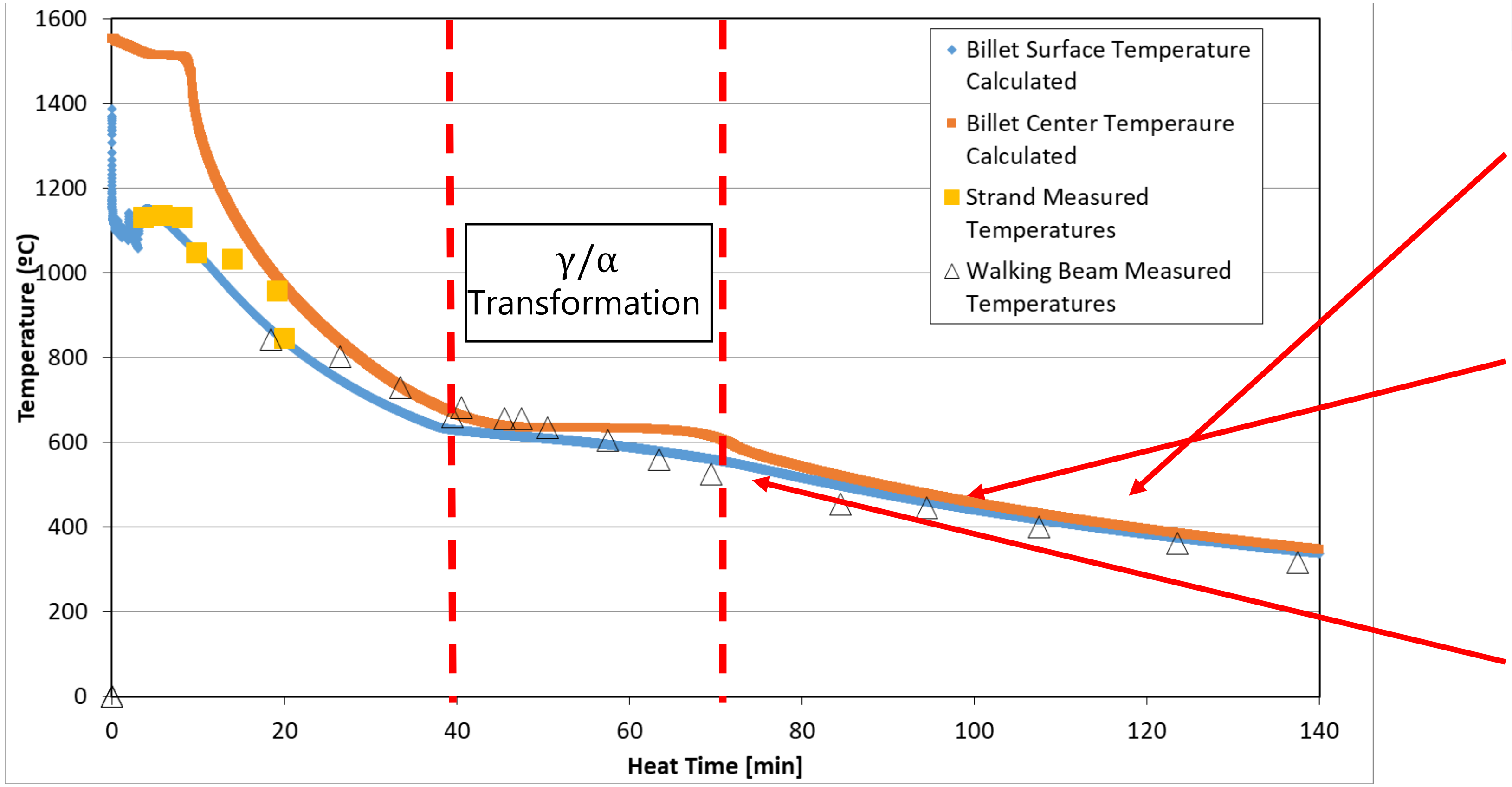
Transformation Stress Cracks at the tertiary cooling

Example: 16MnCr5E



Casting time for different casting conditions

If both heats would have cast 5 strands at 1,75m/min: **118 min**

If both heats would have cast 6 strands at 1,75m/min: **96 min**

If both heats would have cast 6 strands at 1,85m/min: **72 min**

Thank you for your attention!

Questions?

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