VALCRA WORKSHOP ON THE INFFLUENCE OF S AND MICROALLOYED ELEMENTS ON THE SURFACE CRACKING OF CONTINUOS CASTING BILLETS

2. SURFACE CRACKS ON CONTINUOS CASTING BILLETS

INFLUENCE OF SULFUR AND MICROALLOYED ELEMENTS

5th March 2020
Process Department
Sidenor I+D

VALCRA

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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.
5. Conclusions

1. INTRODUCTION

1. Introduction

Surface cracks:

Transversal cracks cracks

Intergranular cracks

Thermal Stress Cracks

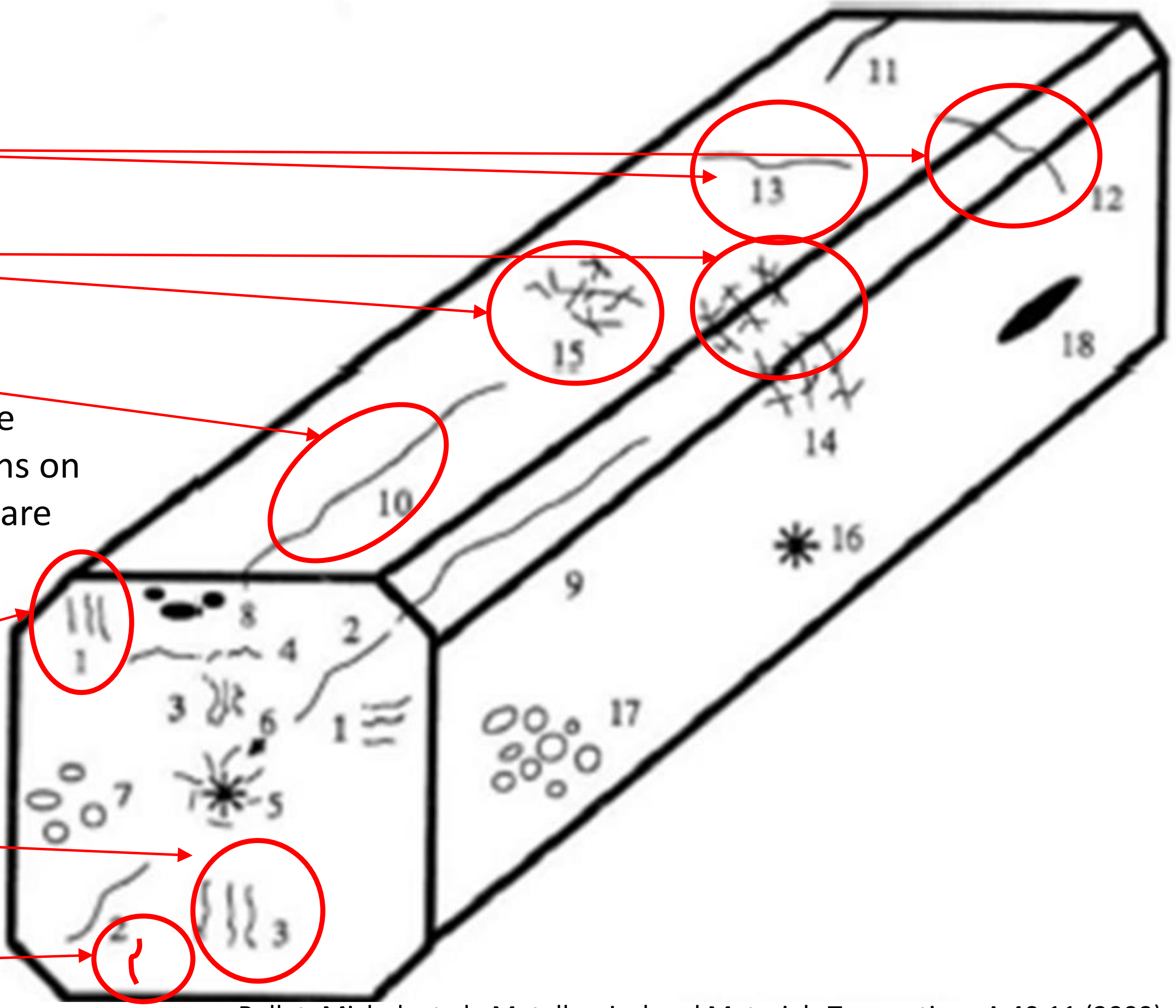
Surface cracks related to micro alloying elements will be studied. Other defects related to solidification conditions on the meniscus (mould powders, oscillation conditions..) are not dealt with in this presentation.

Internal segregation cracks:

Off-corner cracks

Half-way cracks

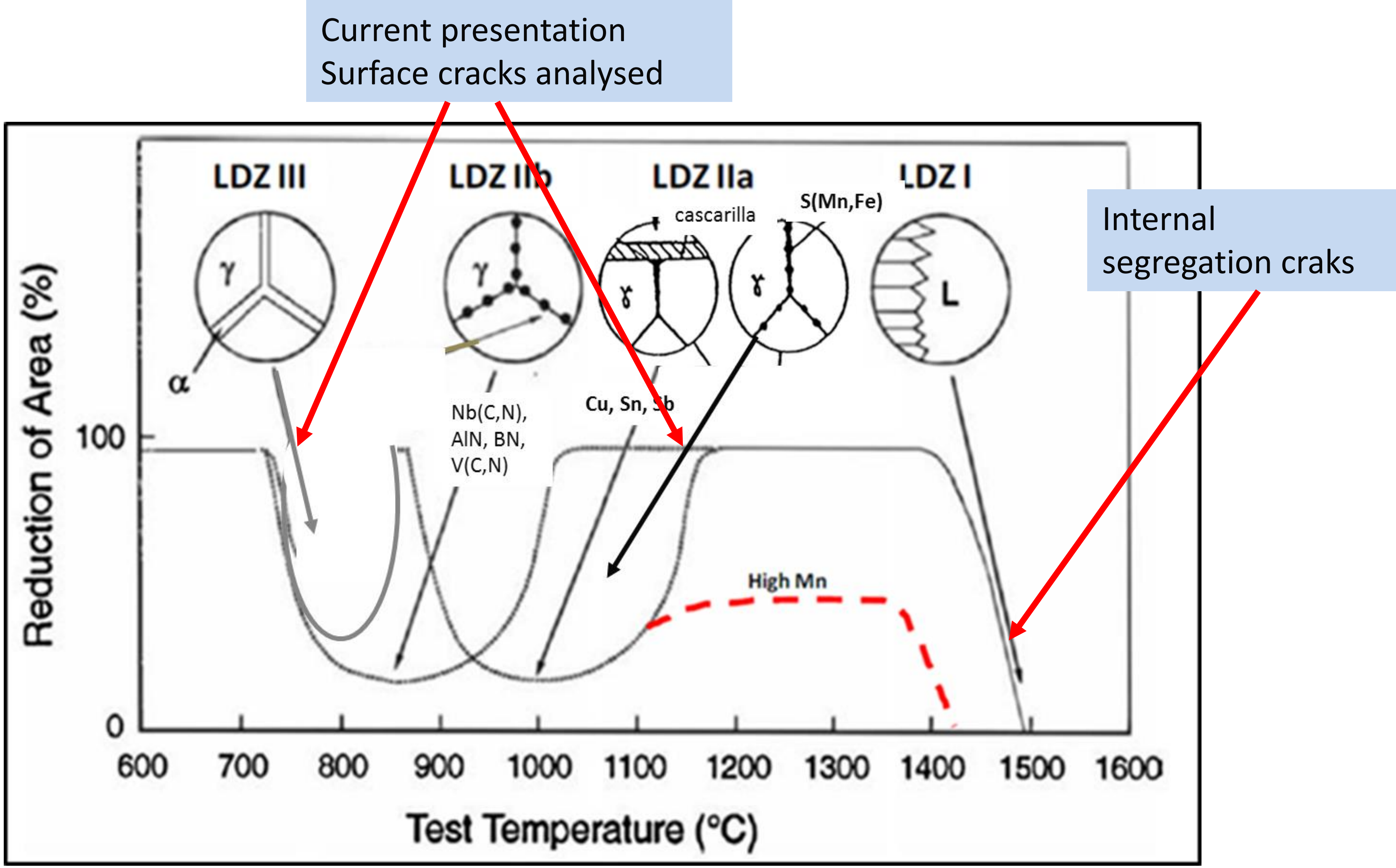
Near-corner Cracks



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

1. Introduction

Low ductility troughs during solidification and cooling. Those ductility troughs influence the continuous casting semis quality.



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

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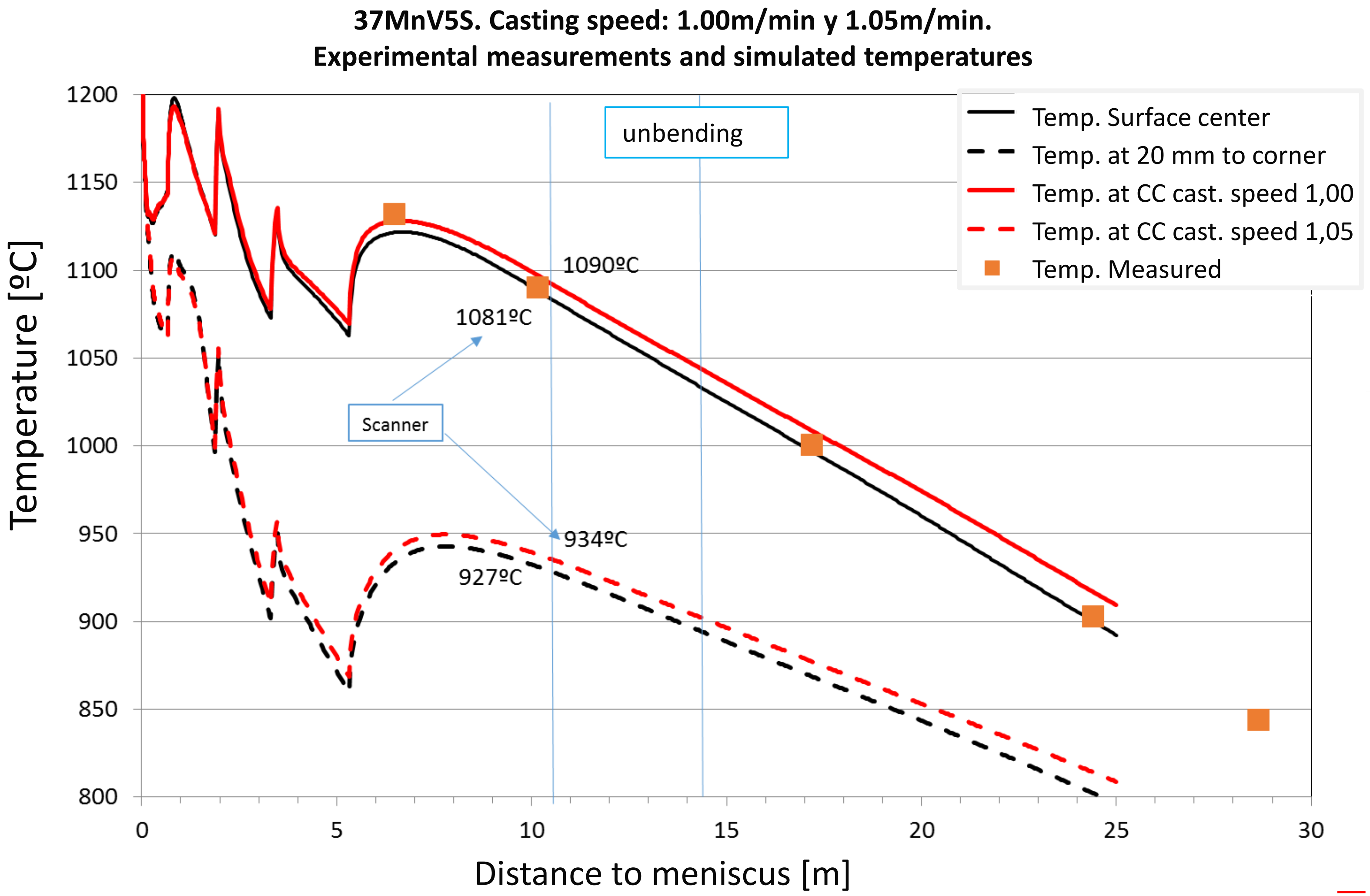
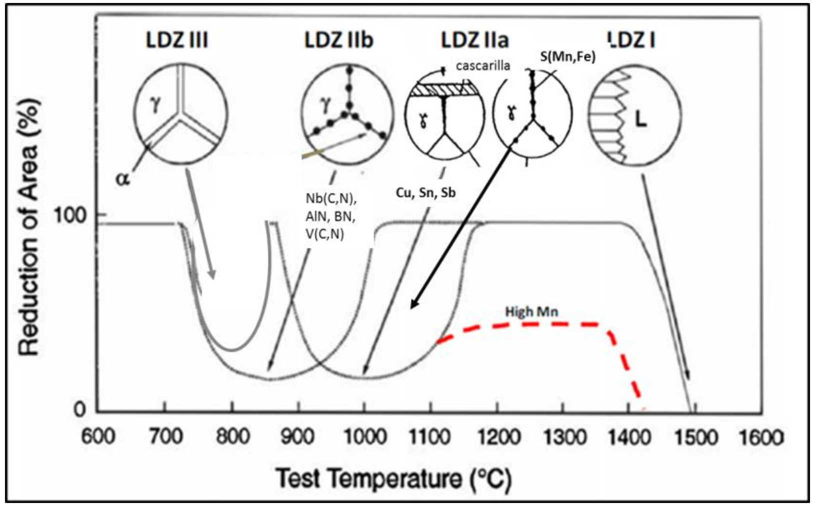
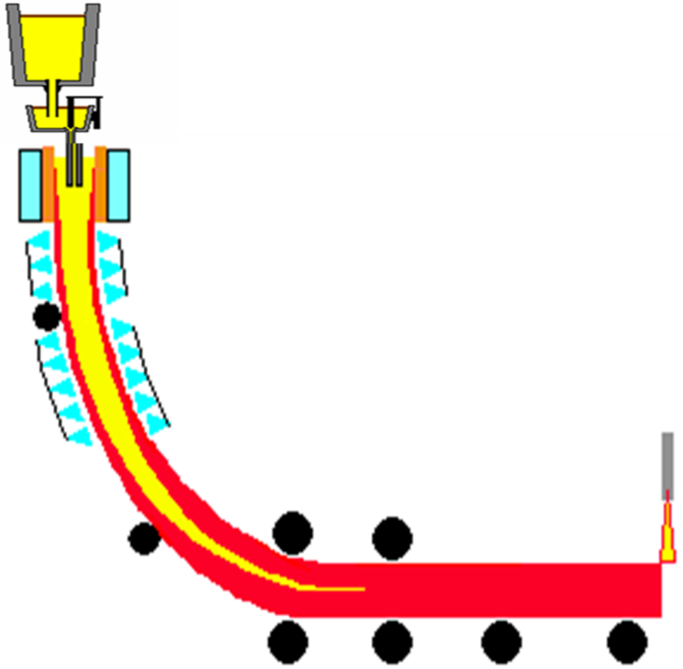
1. Introduction

Evolution of the billet temperature at the CC. Sidenor home made continuous casting solidification program Distemp.







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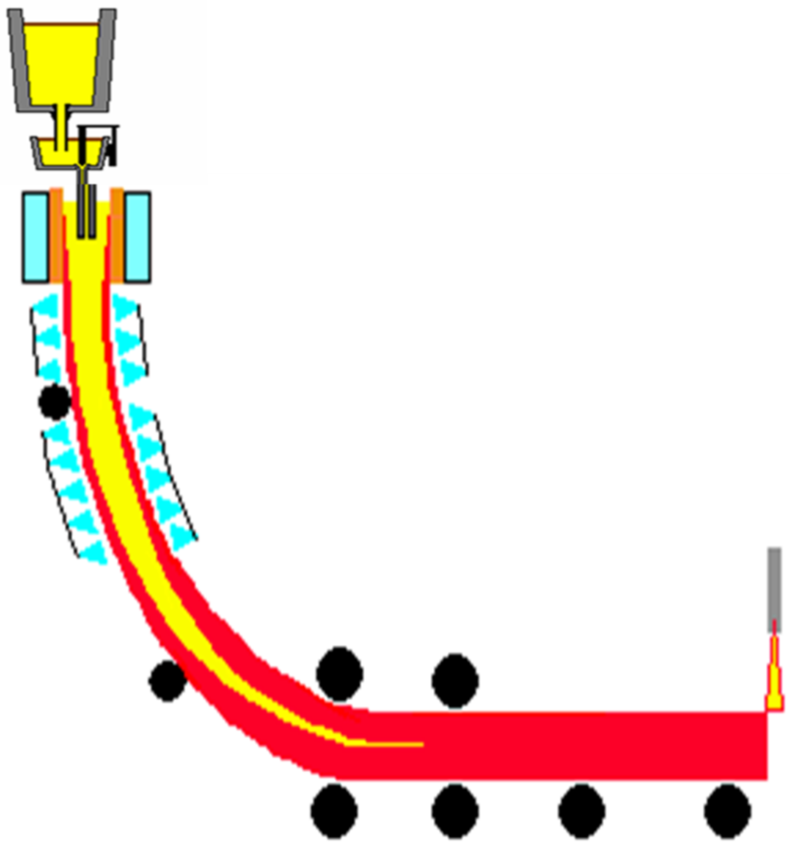
1. Introduction



Strain at the unbending: F/(2*R)
F: Billet section(mm)
R: CC radius (mm)

Strains at the unbending as a function of the number of radii

Billet size (mm)	1 unbending Radii 9 m	2 unbending Radii 9 – 17 m	3 unbending Radii 9 – 12 – 22m
155	0,87%	0,41% 0,46%	0,22% 0,30% 0,35%
240	1,35%	0,64% 0,71%	0,34% 0,46% 0,55%

Continuous Casting Machine design criteria: Increase the casting radius or the number of radius at the unbending in order to obtain a strain lower than 1%

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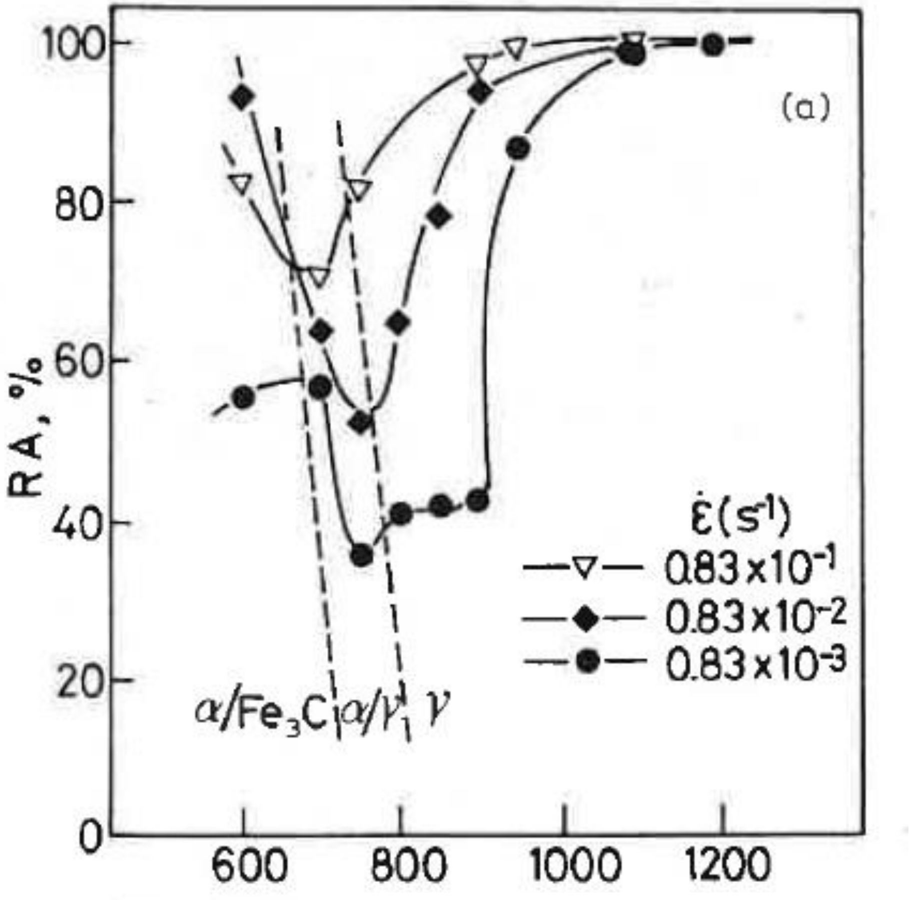
1. Introduction



Temperature [ºC]

0.2% C, 0.30% Si, 1.52% Mn, 0.030% Al, 100 ppm N

Strain at the unbending: F/(2*R)
F: Billet section(mm)
R: CC radius (mm)

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240	1,35%	0,64% 0,71%	0,34% 0,46% 0,55%

Continuous Casting Machine design criteria: Increase the number of radius at the unbending in order to obtain a strain lower than 1% for each radius.

As the strain rate decreases so it does the Reduction of Area. Strain rates at CC I he range: 10^{-3} seg^{-1} - 10^{-4} seg^{-1}

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

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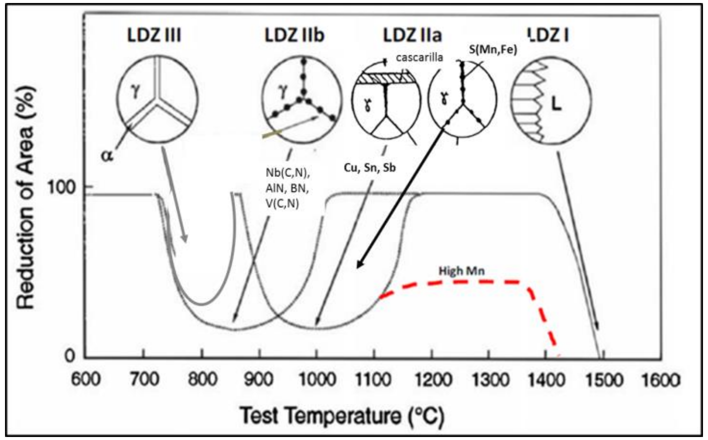
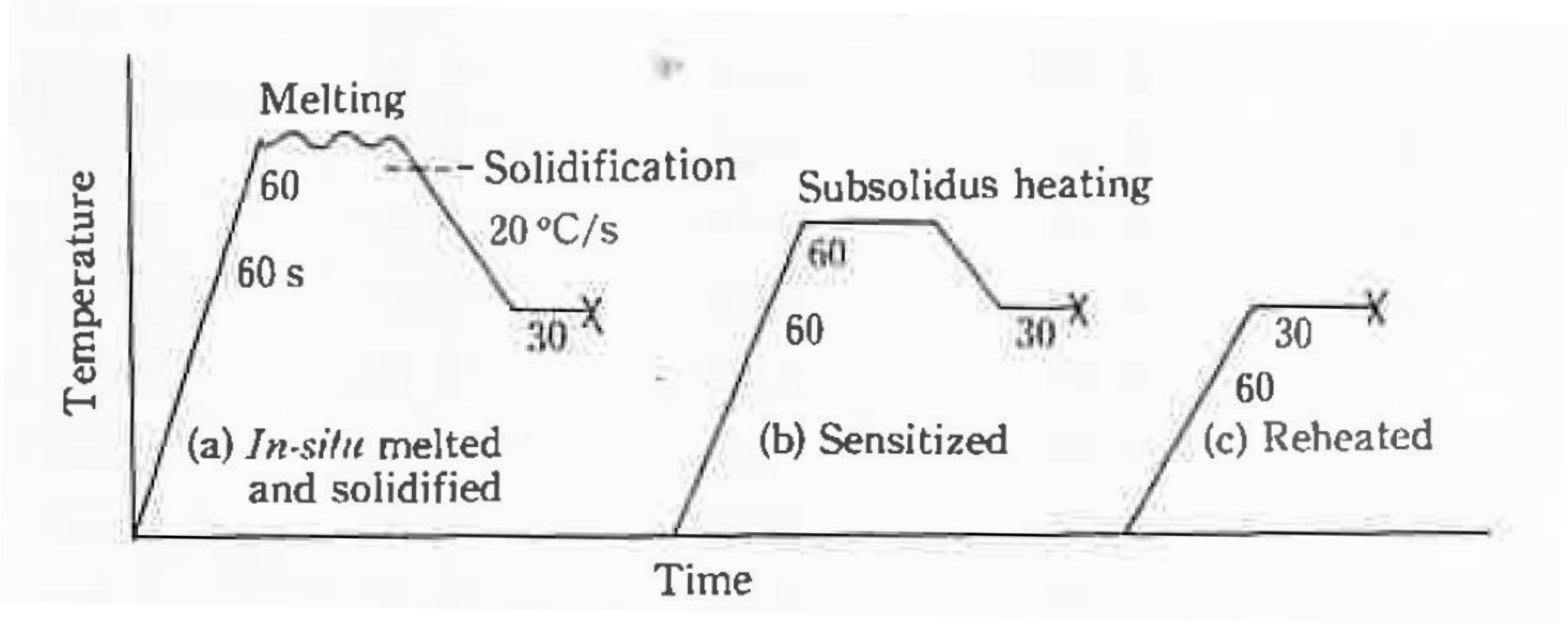
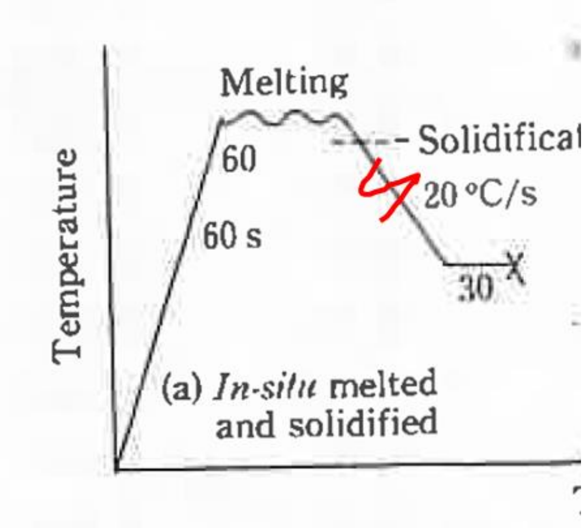
1. Introduction

Since 1980, many ductility experiments have been carried out with the aim of characterizing the different low ductility zones obtained during solidification and cooling of steel.







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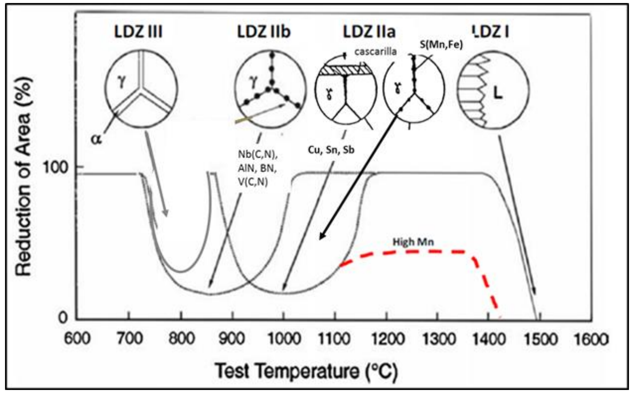
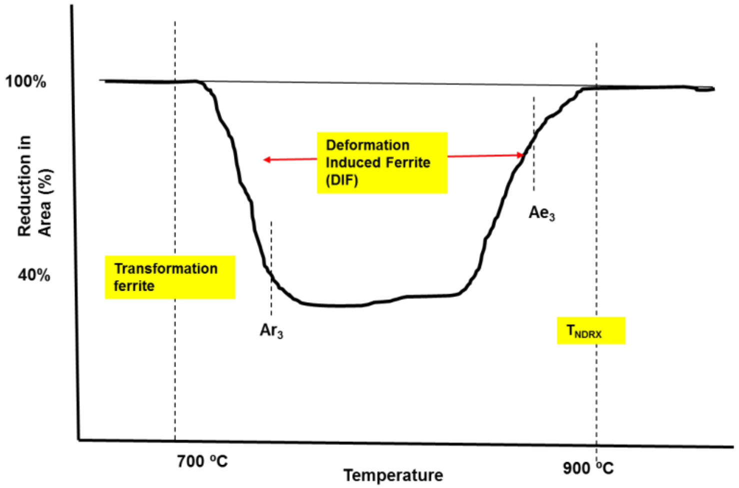
2. INFLUENCE OF THE γ/α TRANSFORMATION AND OF THE AUSTENITIC GRAIN SIZE ON CRACKING

2. Influence of the γ/α transformation and of the austenitic grain size on cracking



Low ductility trough for steel tested at low strain rates. (plain C-Mn steels)



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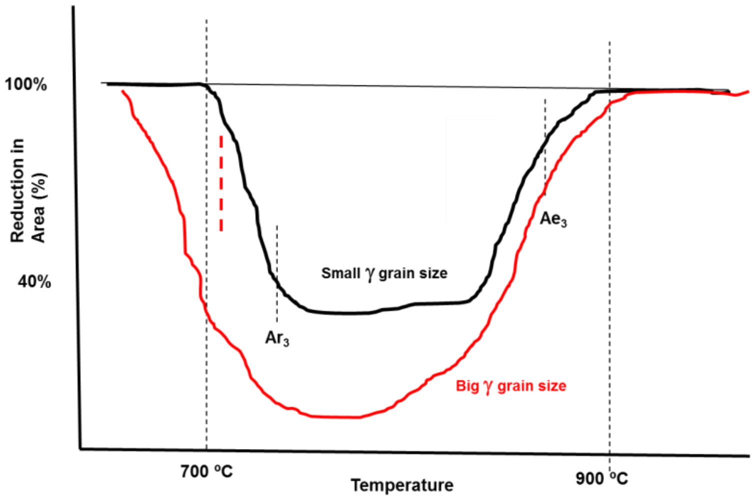
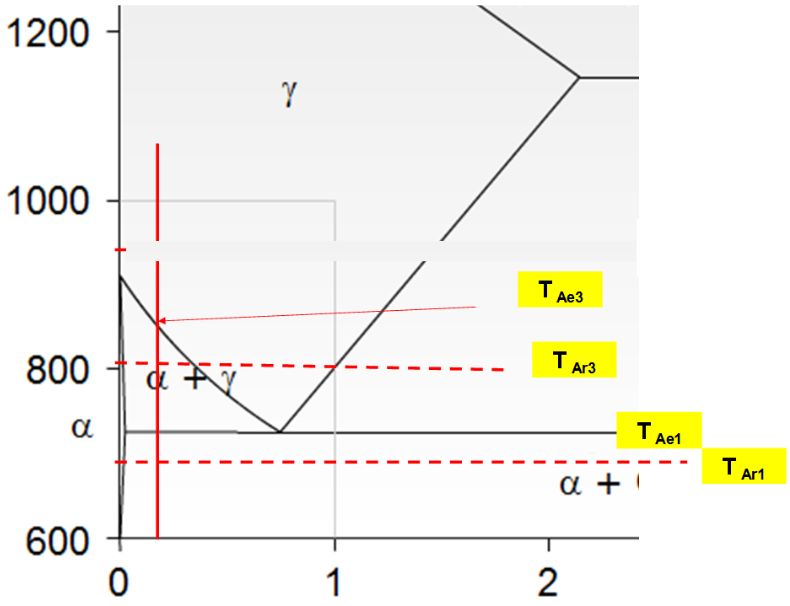
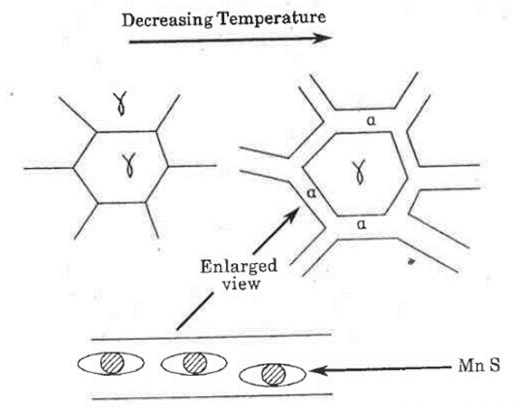
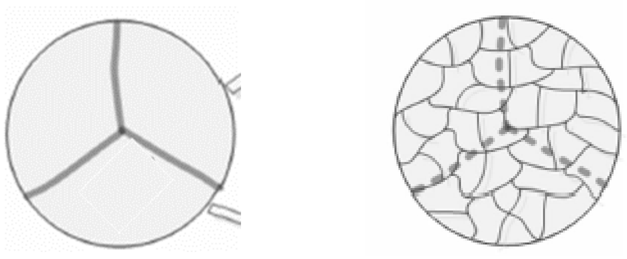






6 Schematic diagram showing mechanism for transformation induced intergranular failure

Austenitic Grain size

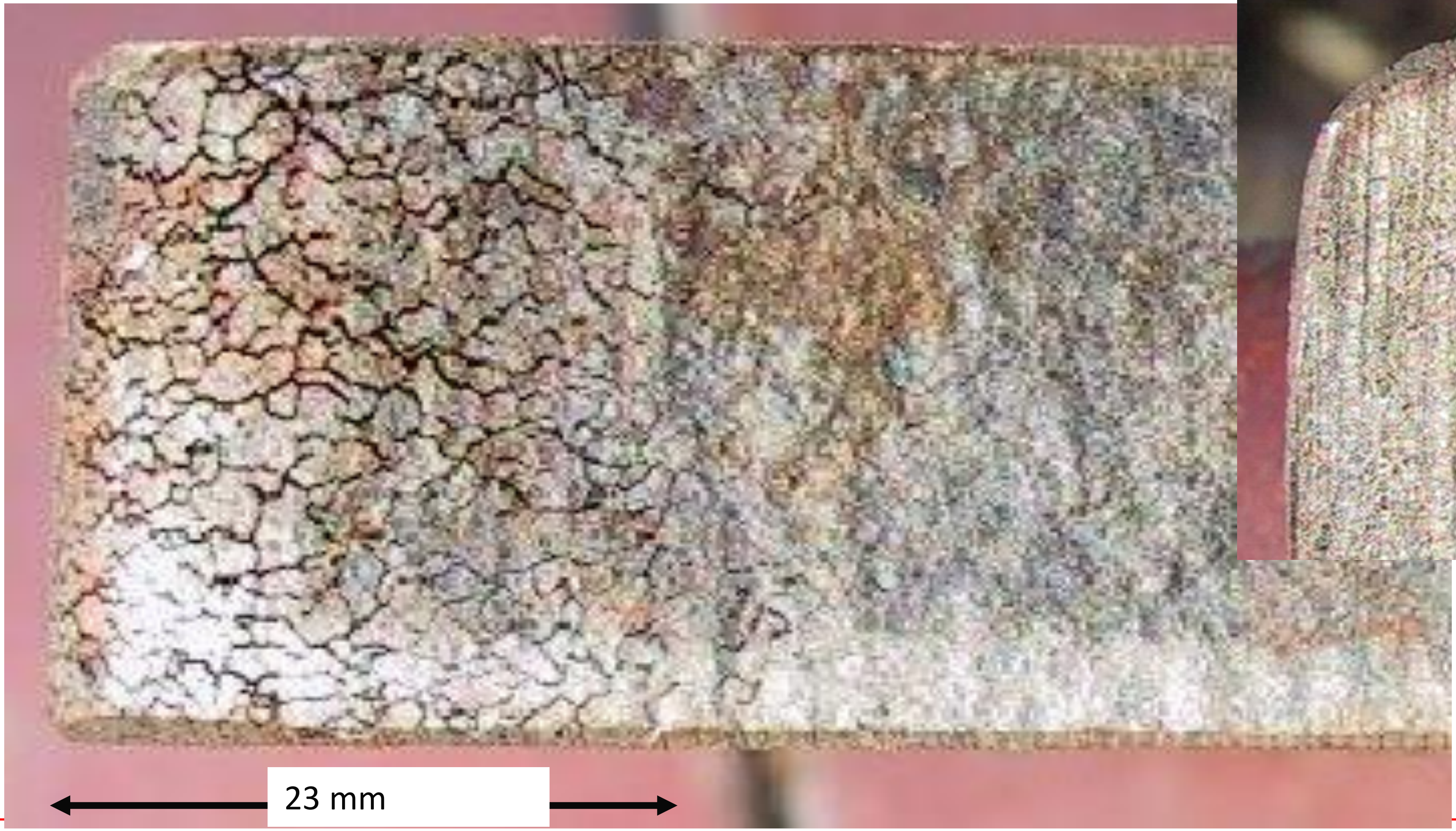


Big

Small

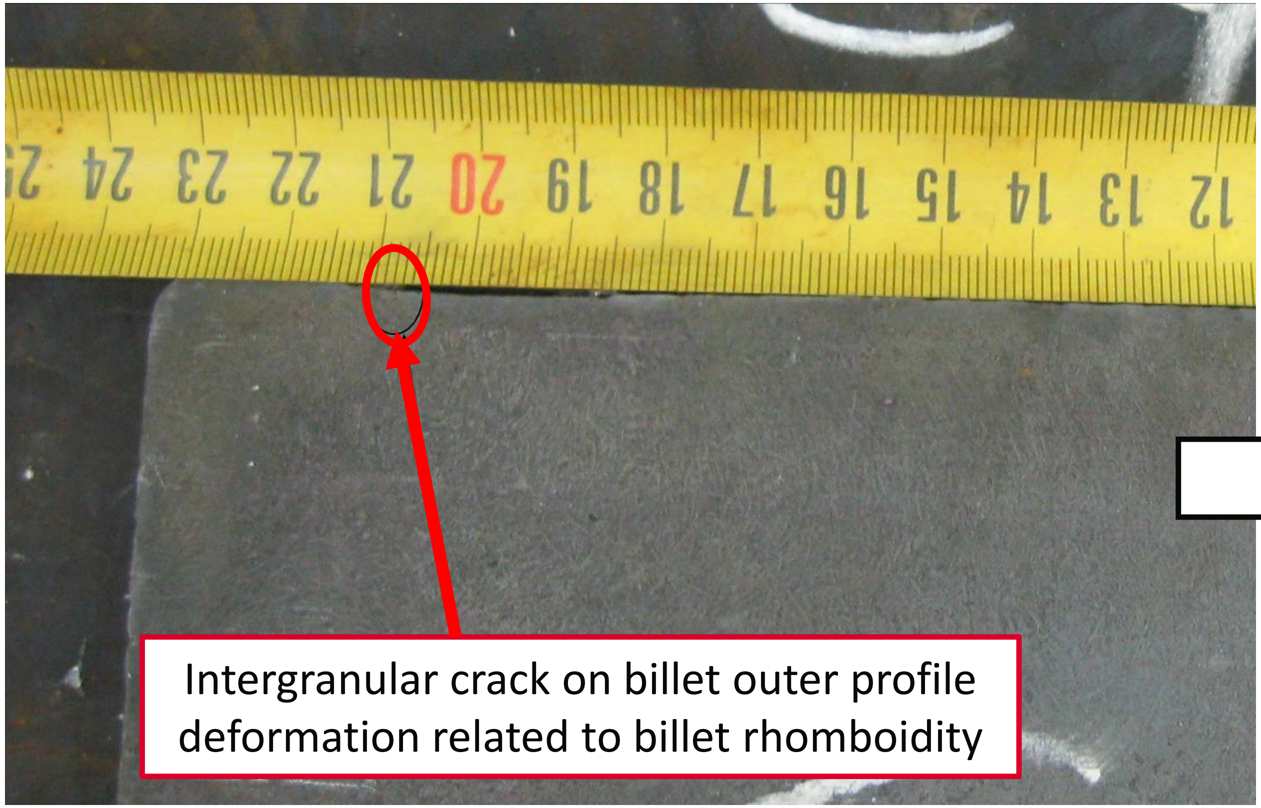
2.Influence of the γ/α transformation and of the austenitic grain size on cracking

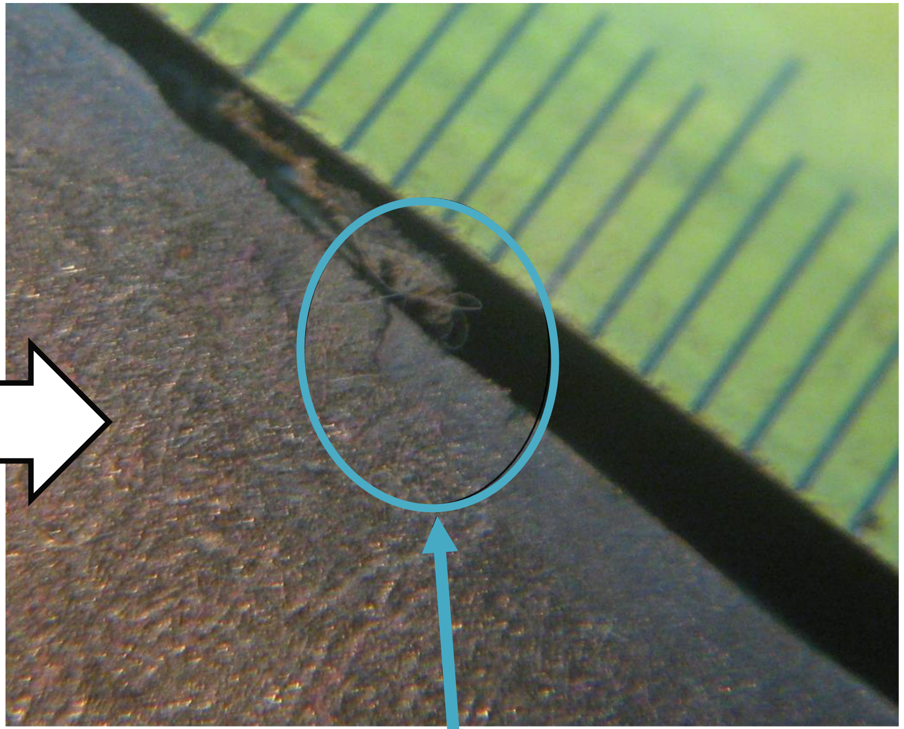
Billet corner of sample S3B4, 19MnNbV5C steel grade.
Hot acid etching



2. Influence of the γ/α transformation and of the austenitic grain size on cracking

37MnV6S Billet transversal slice





Intergranular crack depth: 2mm

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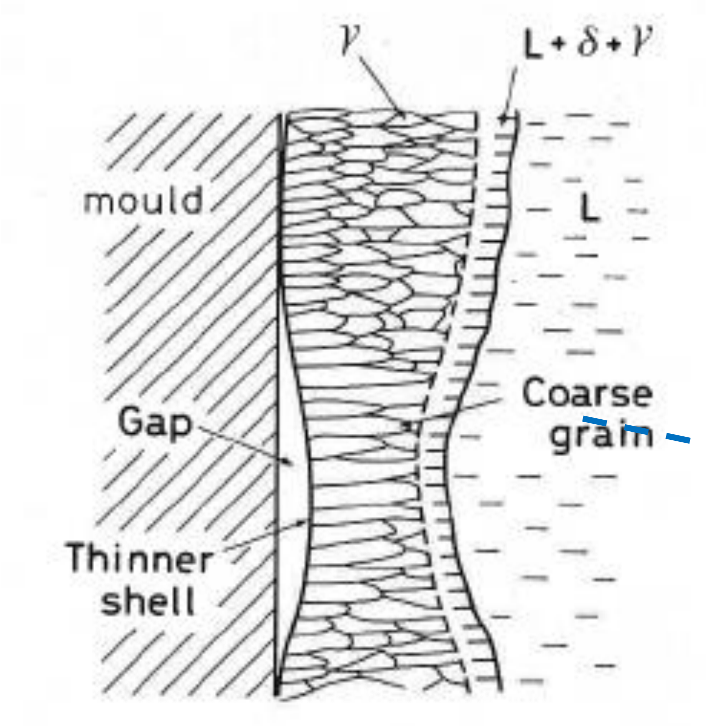
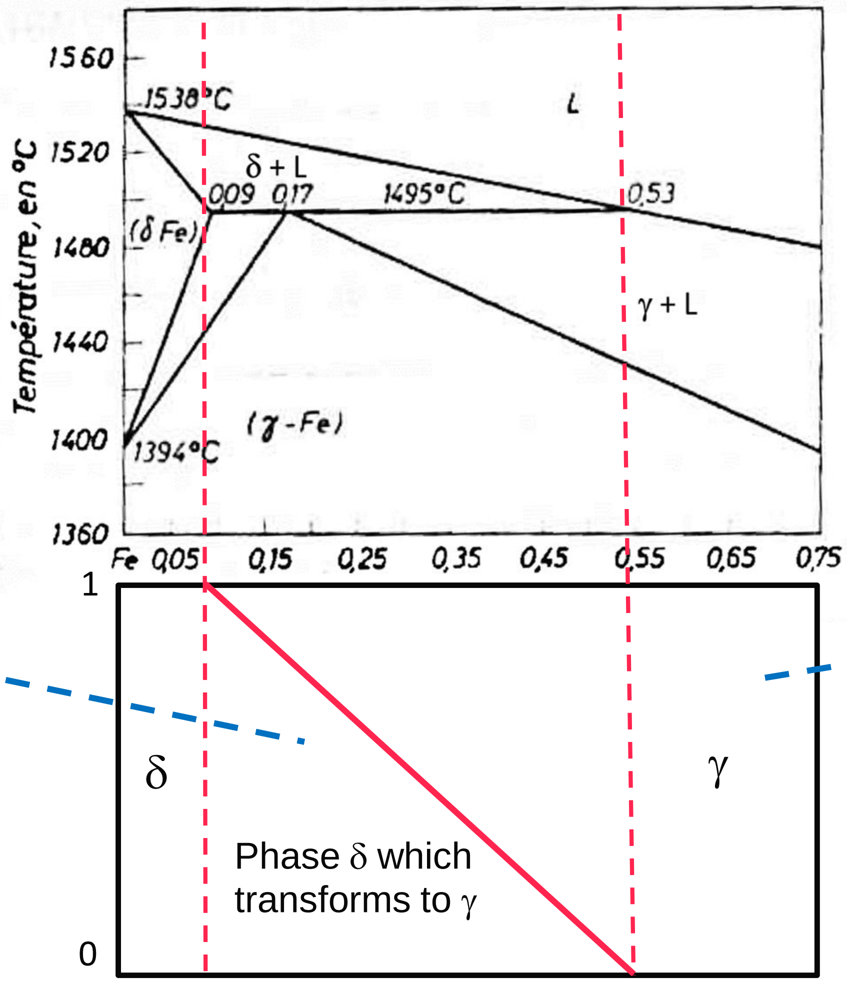
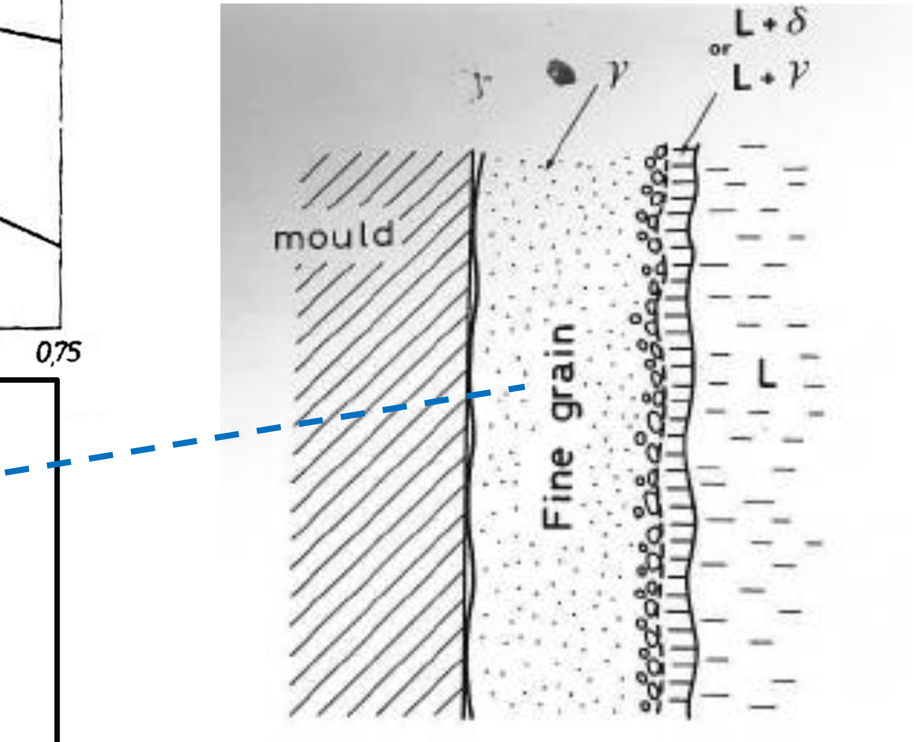
2. Influence of the γ/α transformation and of the austenitic grain size on cracking

Steel composition influence on austenitic grain size:







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

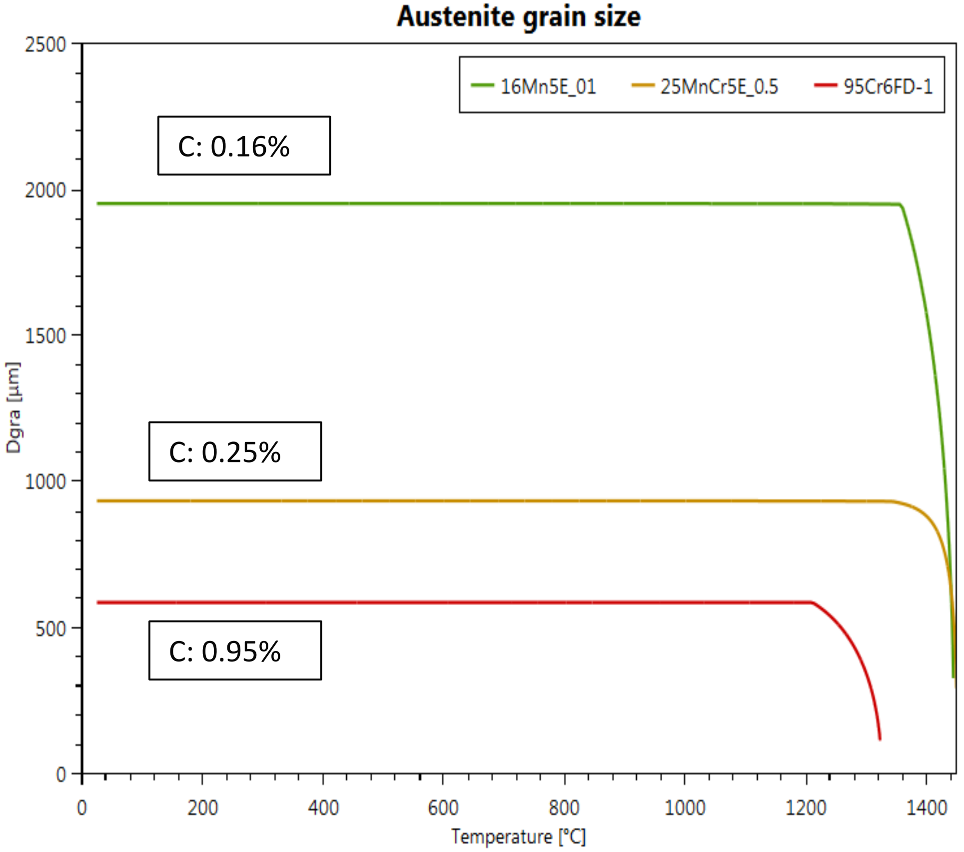
Carbon equivalent for peritectic reaction

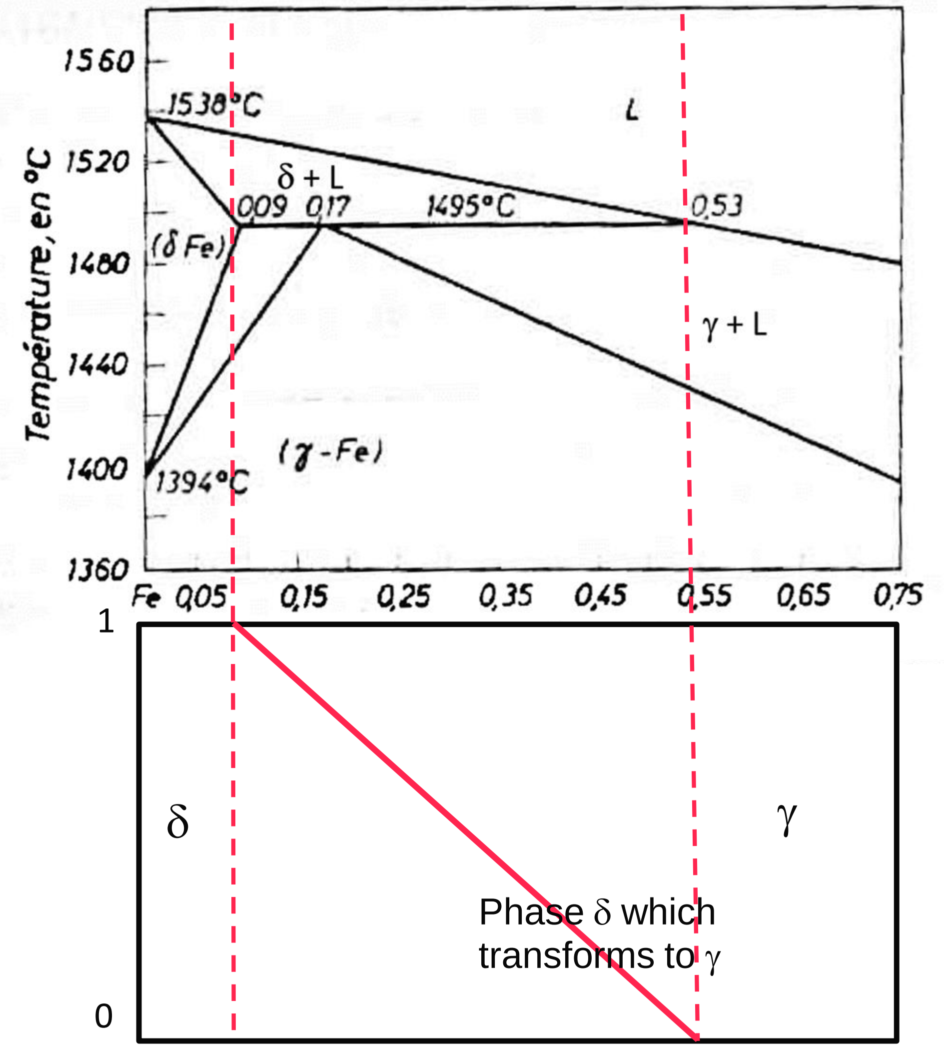
Cp = C +0,02*Mn+0,04*Ni-0,1*Si-0,04*Cr-0,1*Mo-0,7*S

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

2. Influence of the γ/α transformation and of the austenitic grain size on cracking

IDS calculations of austenitic grain size for steel grades with different carbon content. Cooling rate during the solidification: 0.5ºC/seg

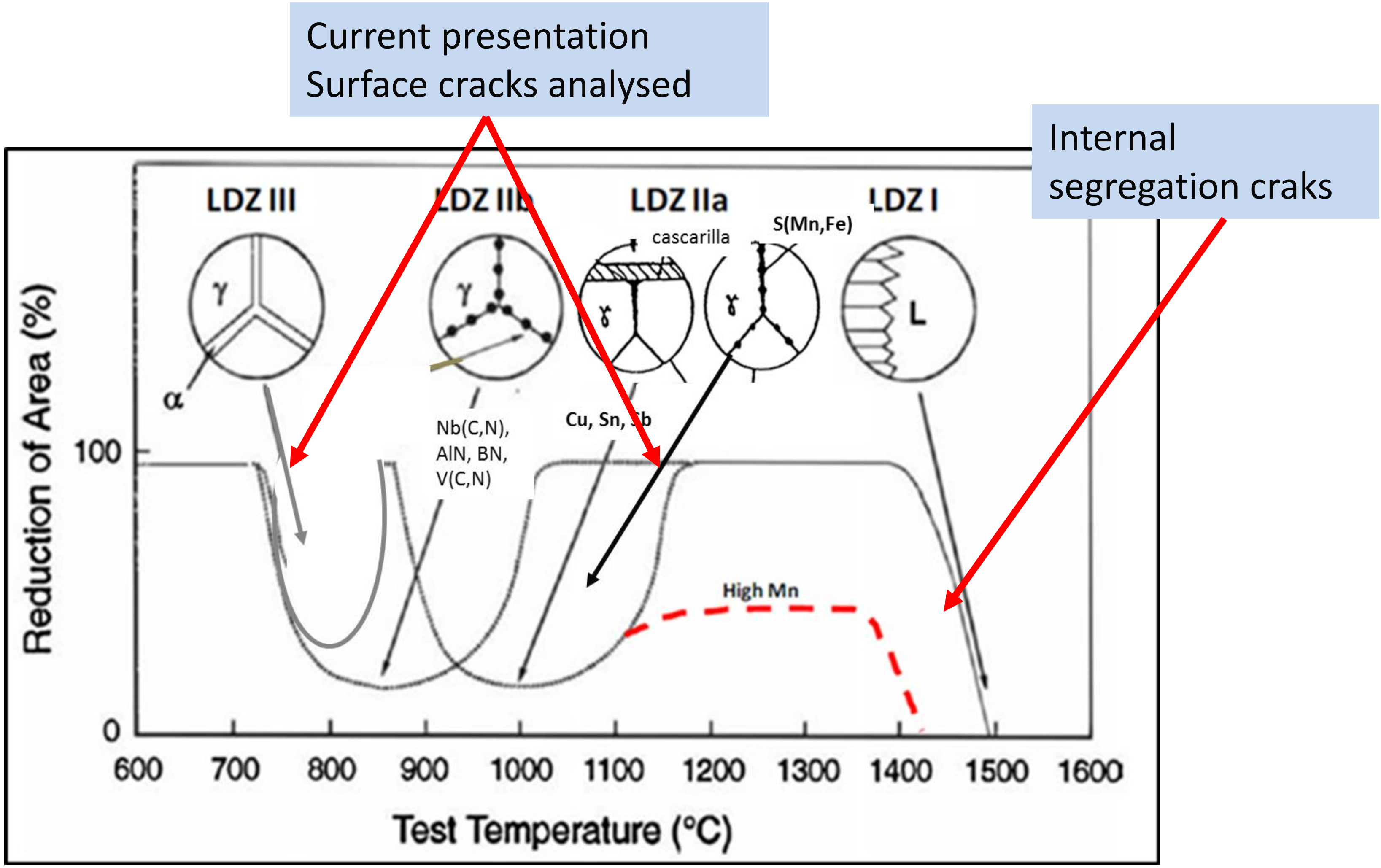




3. INFLUENCE OF THE MICROALLOYING ELEMENTS ON HOT DUCTILITY.

3. Influence of the microalloying elements on hot ductility.

Low ductility troughs during solidification and cooling. Those ductility troughs influence the continuous casting semis quality.



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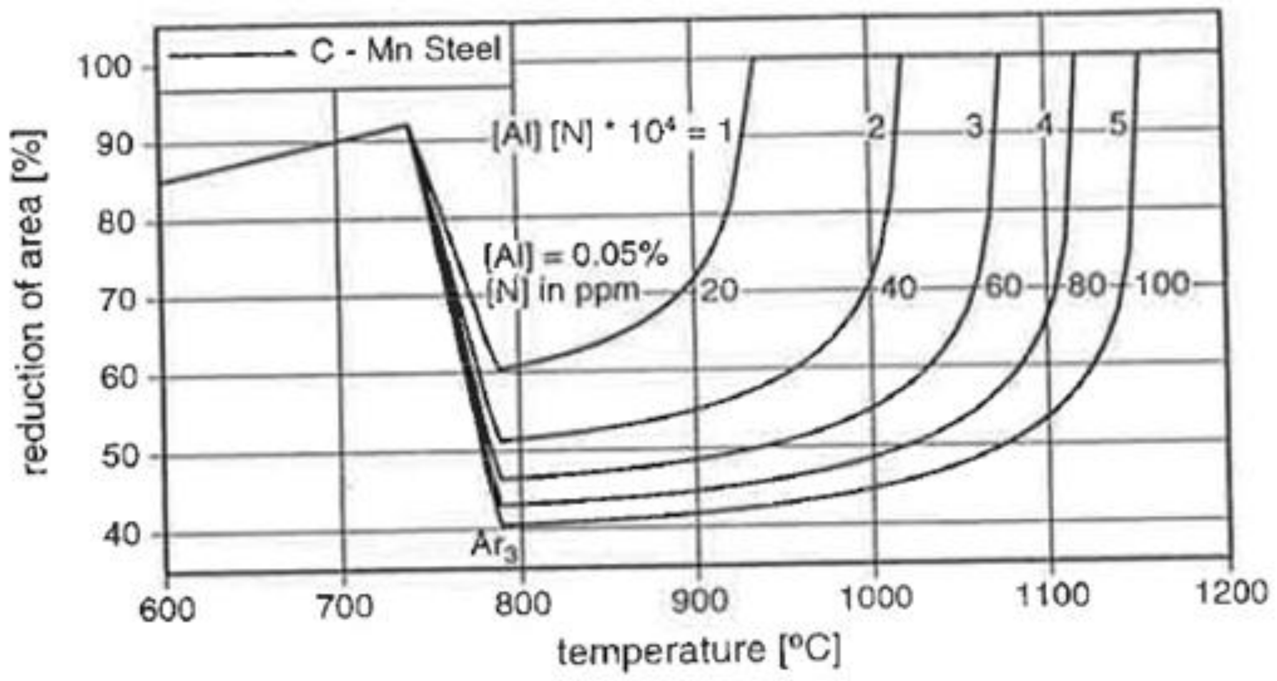
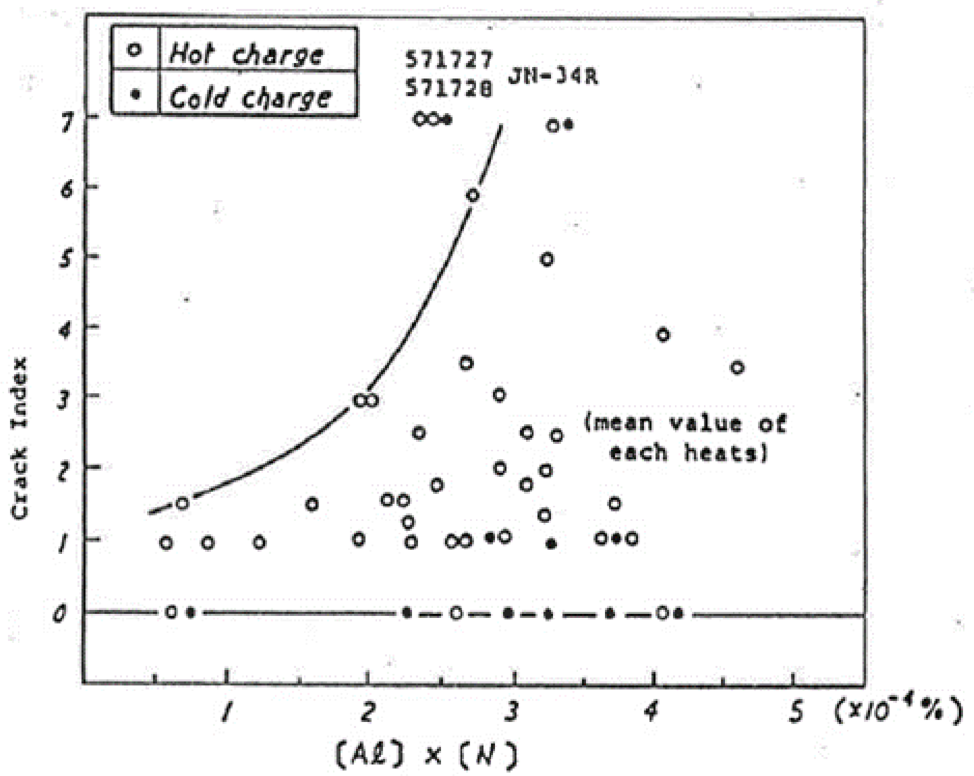
3. Influence of the microalloying elements on hot ductility.

1. 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 temperatuires.



Relationship between crack index and the N*Al product. Daido steel

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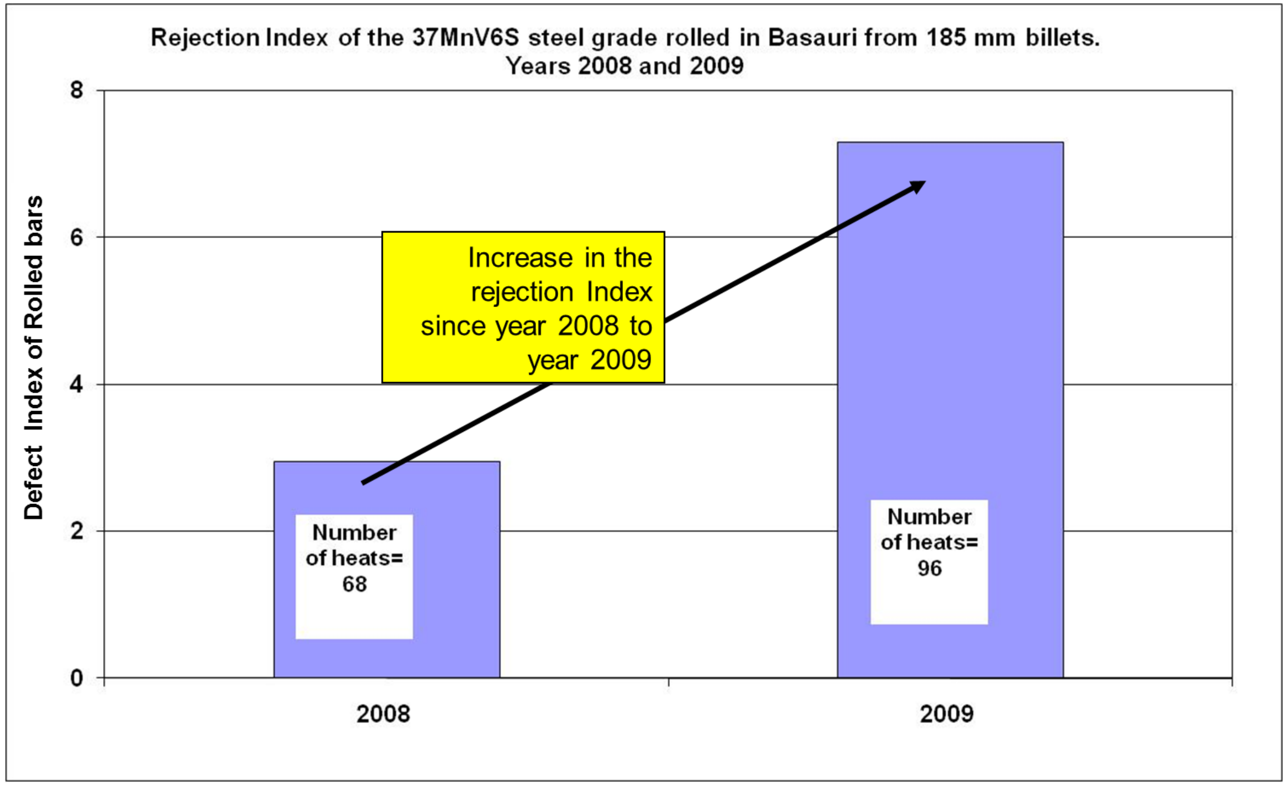
3. Influence of the microalloying elements on hot ductility.

1. Influence of the AlN

In 2008 and 2009 at Sidenor an increase of rejection index of the steel grades 37MnV6S and 37MnV6E was observed.



37MnV6S and 37MnV6E composition

C	Mn	Si	P	S	Cr	Ni	Mo	V	Al	Ti	N
0.36	1.35	0.58	0.017	0.070	0.14	0.09	0.02	0.10	0.015	<0.007	120

C	Mn	Si	P	S	Cr	Ni	Mo	V	Al	Ti	N
0.36	1.35	0.58	0.017	0.045	0.14	0.09	0.02	0.10	0.015	0.015	120

3. Influence of the microalloying elements on hot ductility.

1. Influence of the AlN

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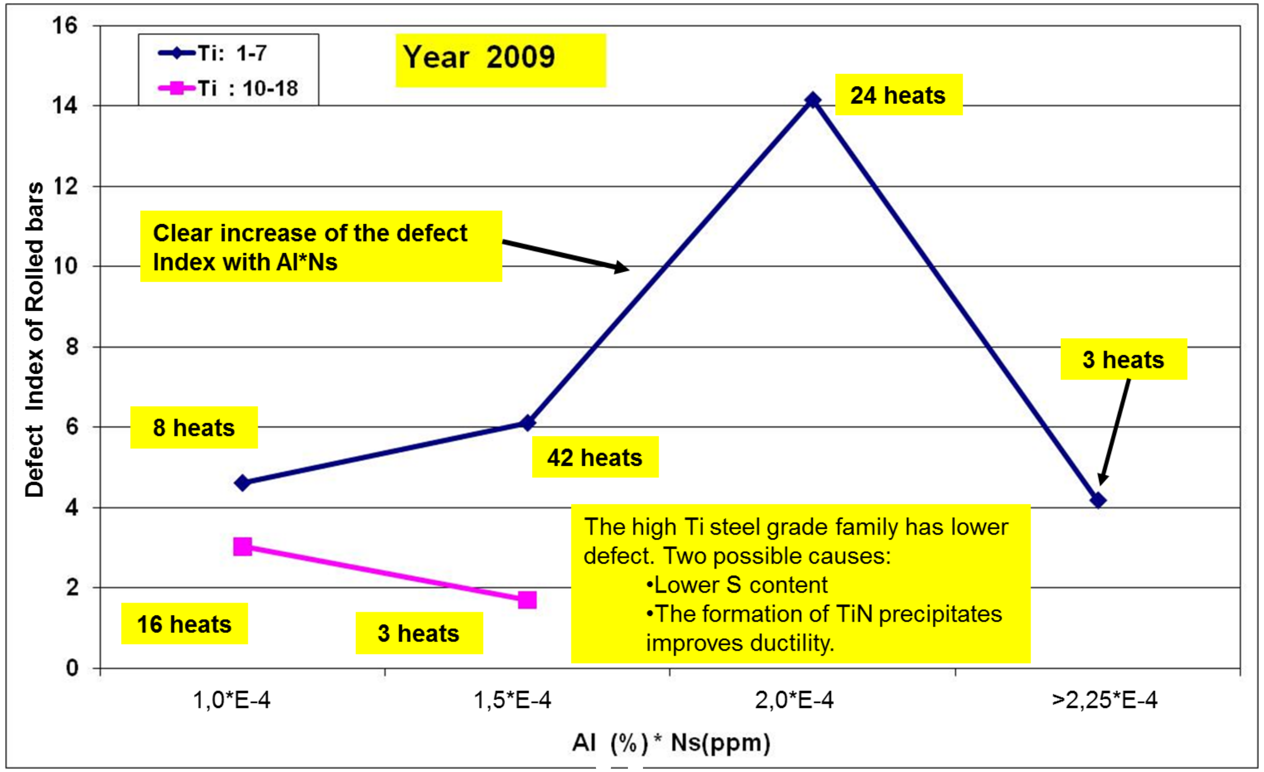

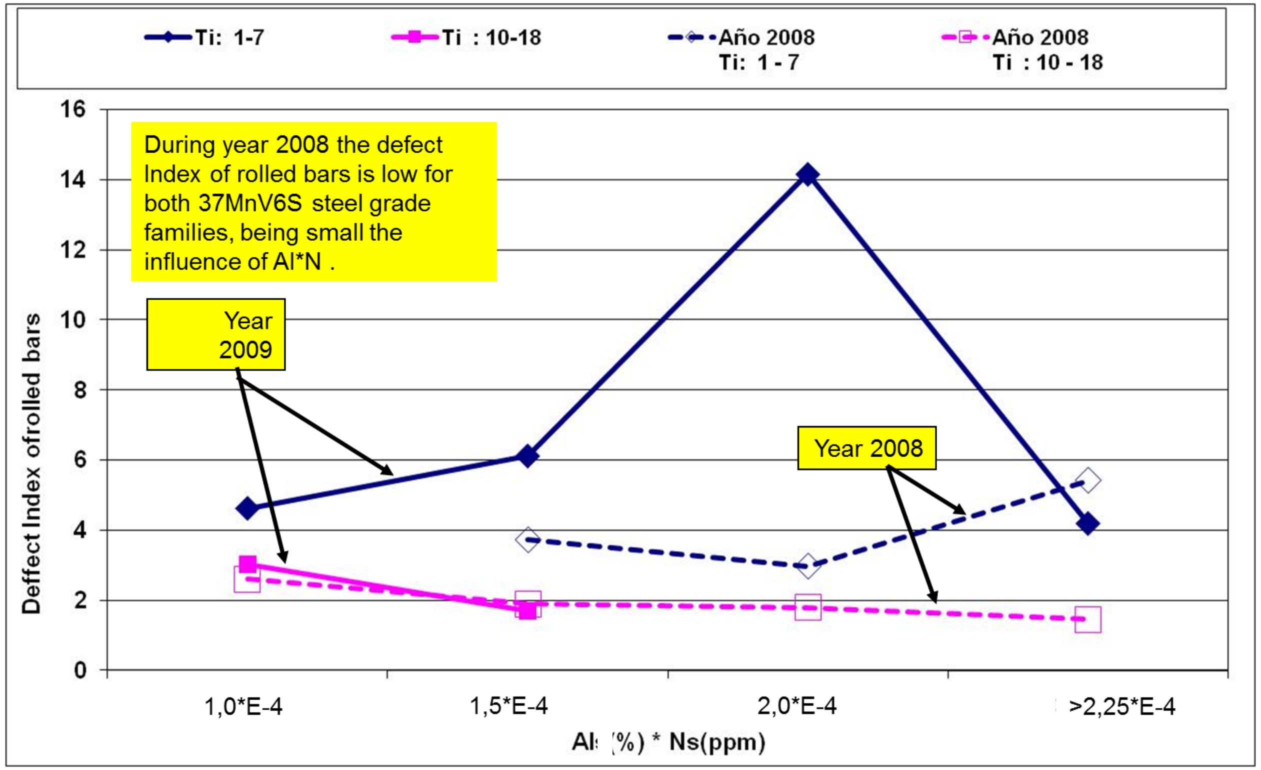

In order to decrease the steel tendency to cracking, the Ti content should be as high as possible in the range of the steel grade specification.

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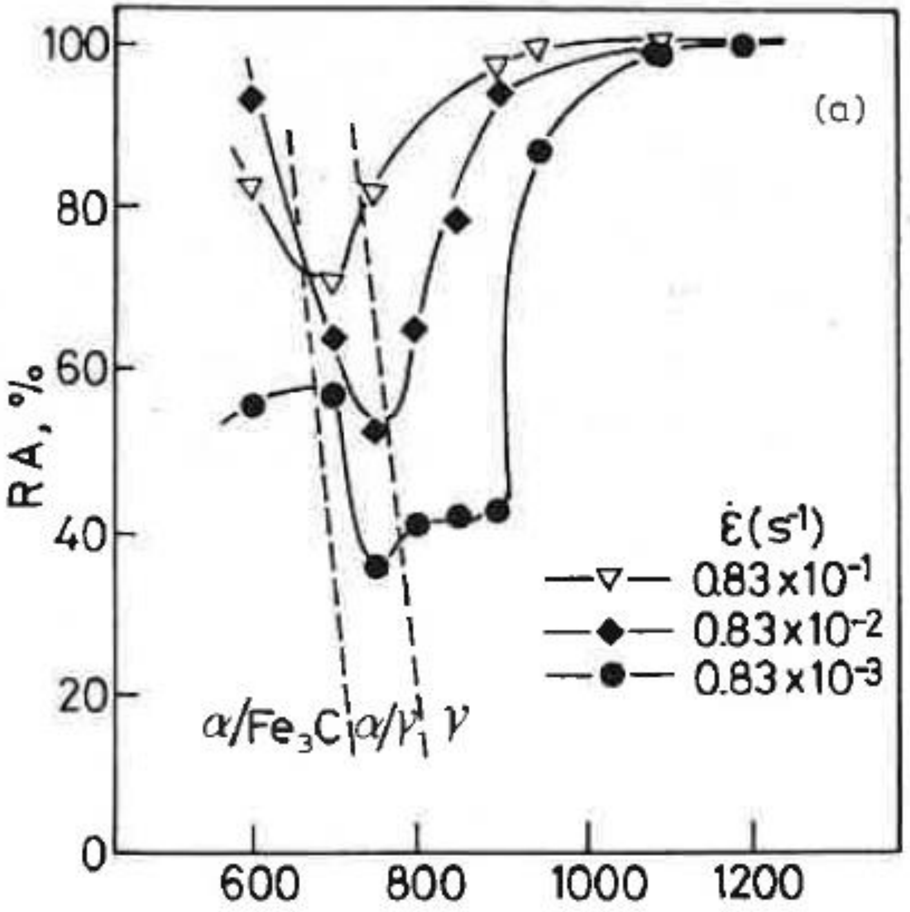
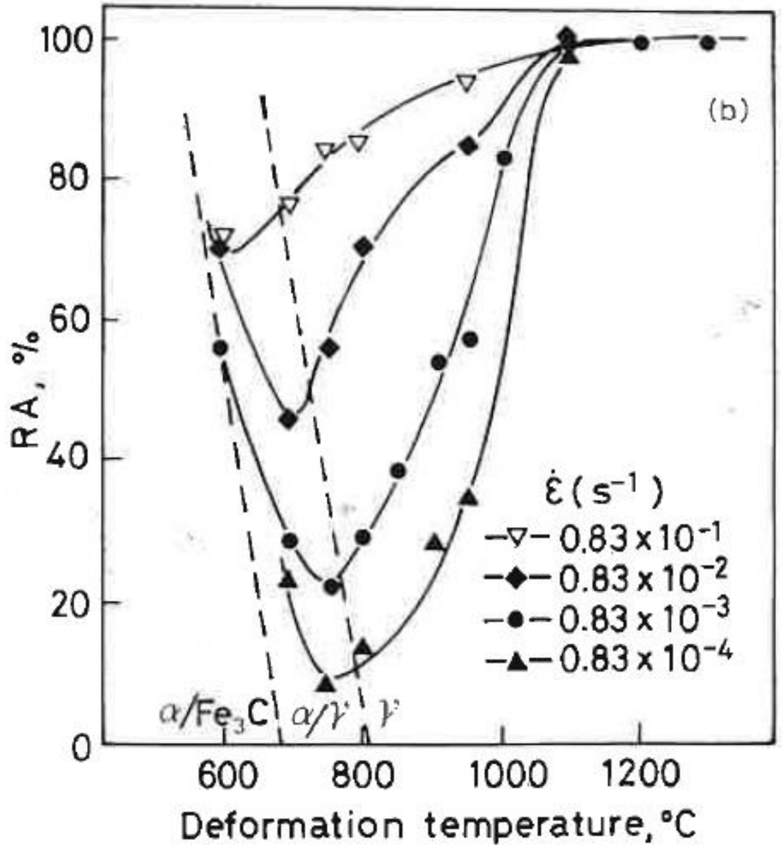
3. Influence of the microalloying elements on hot ductility.

2. Influence of Nb(C,N)



0.2% C, 0.30% Si, 1.52% Mn, 0.030% Al, 100 ppm N



0.2% C, 0.30% Si, 1.50% Mn, 0.010% Al, 30 ppm N, 0.050%Nb

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

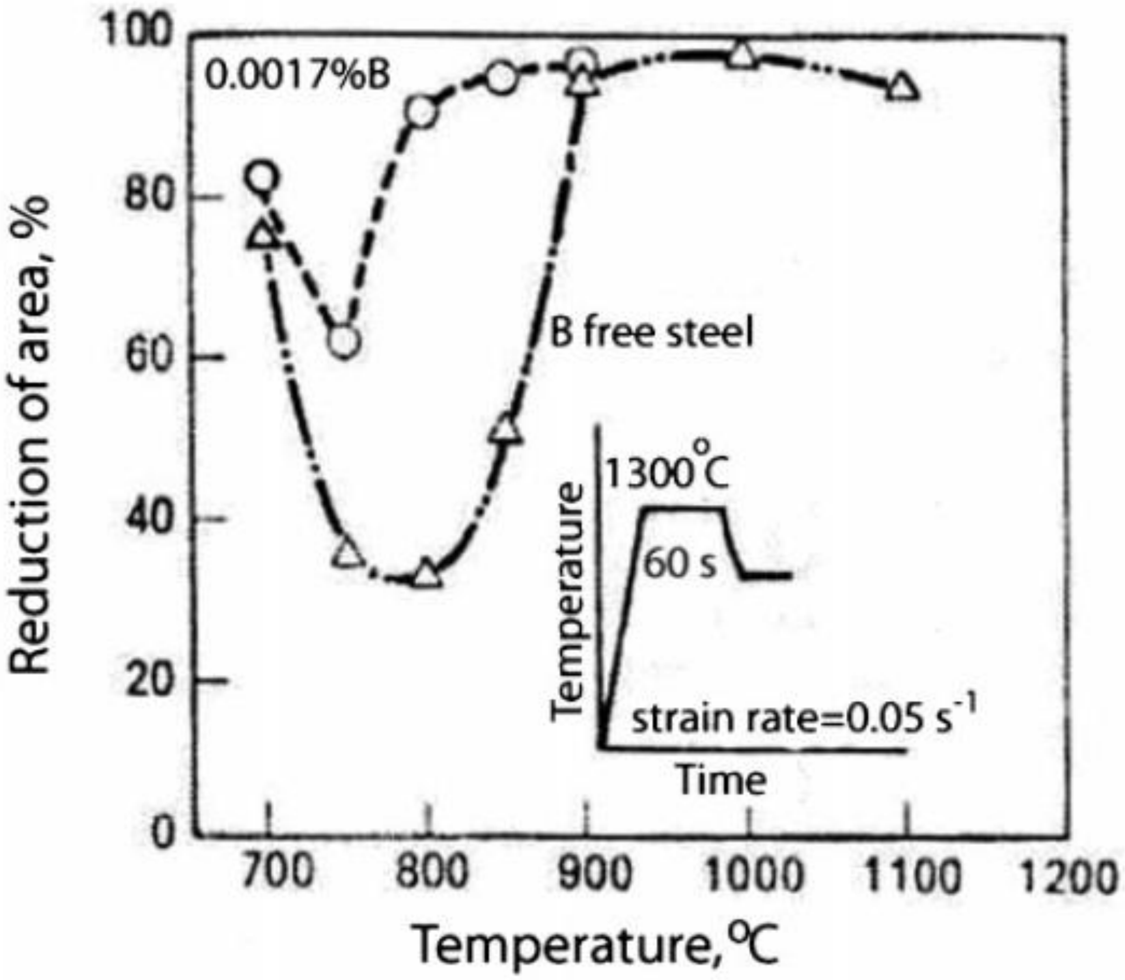
The ductility trough depth and extent is higher for the Nb steel grade than for the Al-N steel grade

3. Influence of the microalloying elements on hot ductility.

3. Influence of Boron

The hot ductility behaviour of a 0·15%C, 0·65%Mn, 0·02%Al steel, with and without a boron addition. The B addition was 0·0017% and the cooling rate 6 K min^{-1} (Ref. 73)

The B improvement of ductility is related with B diffusion to austenite grain boundaries as temperature decrease, hindering the ferrite intergranular precipitation at grain boundaries, which causes ductility drop.



K. Yamamoto, H. G. Suzuki, Y. Oona, N. Nodec, T. Inoue, Tetsu-to-Hagane, 1987, 73, (1), 111–122.

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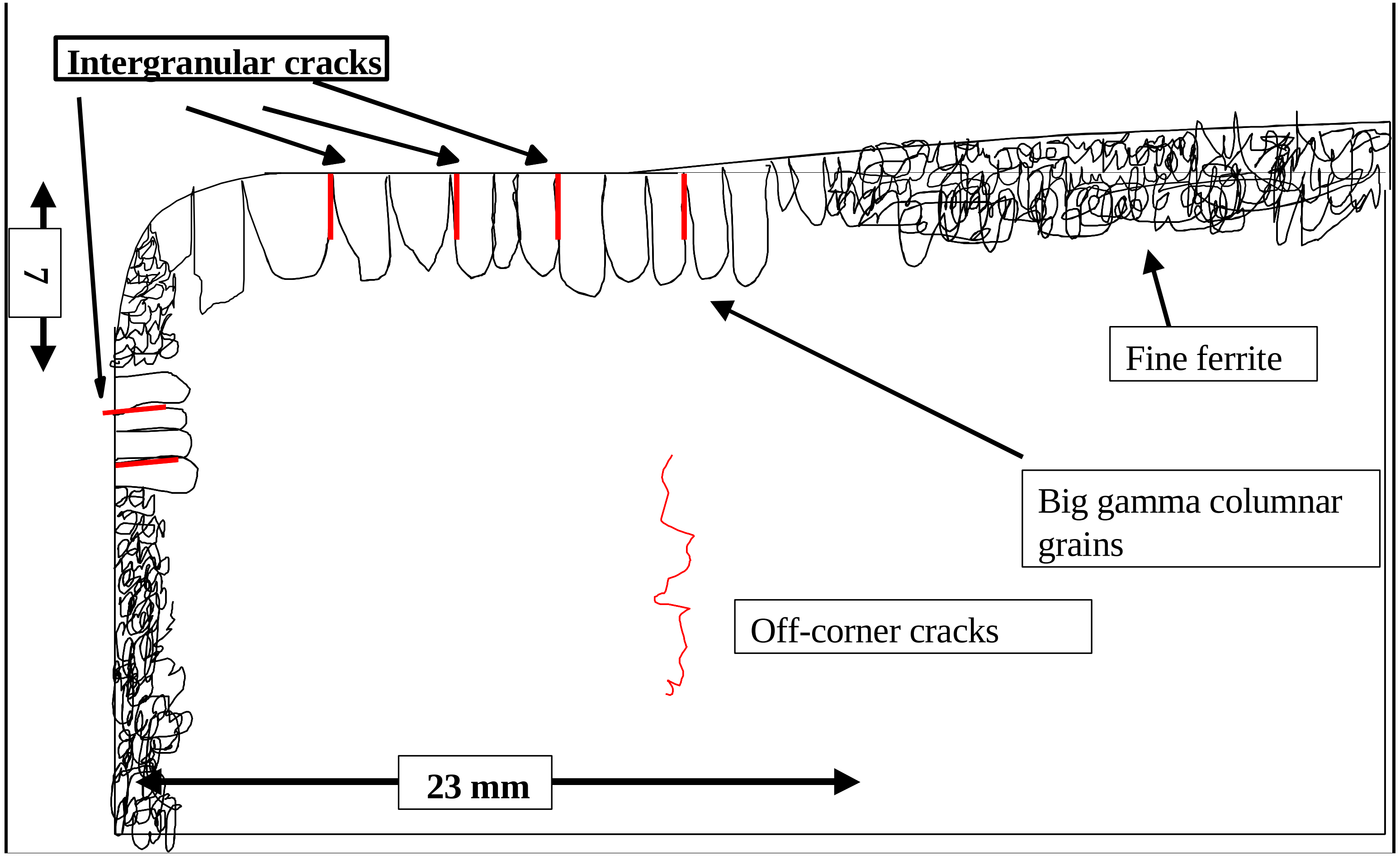
4. METHODS TO AVOID INTERGRANULAR CRACKING: ON-LINE DOUBLE γ/α TRANSFORMATION AND SECONDARY COOLING INFLUENCE.

4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Intergranular cracks :19MnNbV5C steel. Billet as cast microstructure observations.



G. Alvarez de Toledo, J.J. Laraudogoitia, A. Arteaga.
Trans Tech Pub. Ltd. Switzerland. Materials Science Forum Vol. 500-501, 2005.
Microalloying for new steel processes and applications.
Pp:163-170 2005

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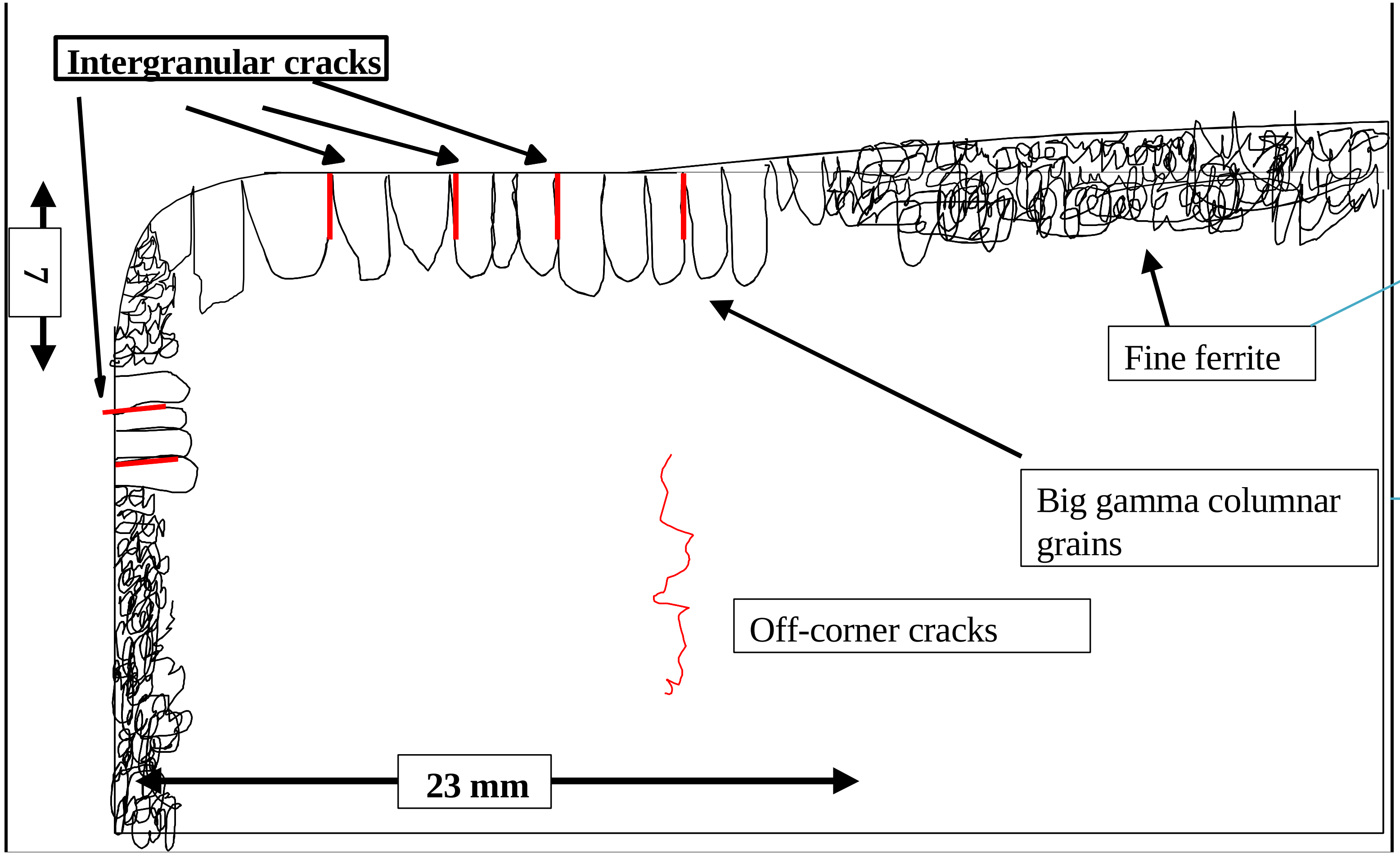

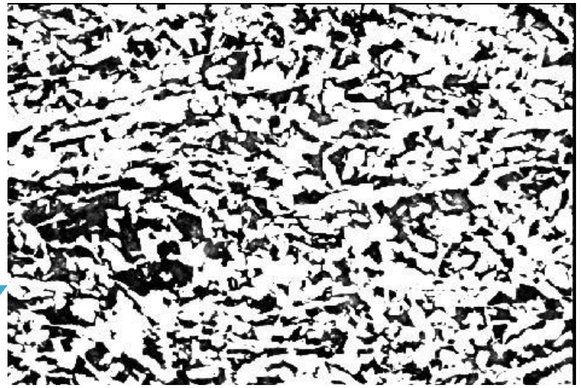

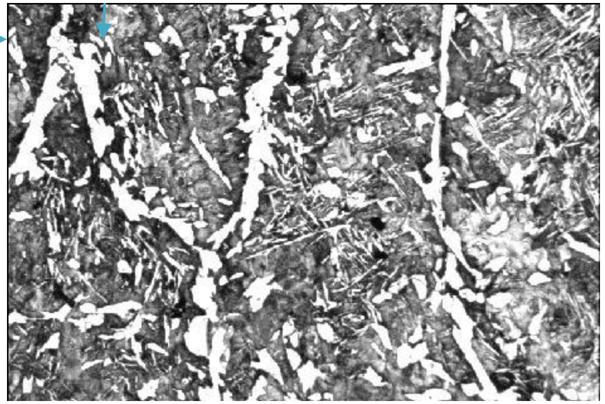

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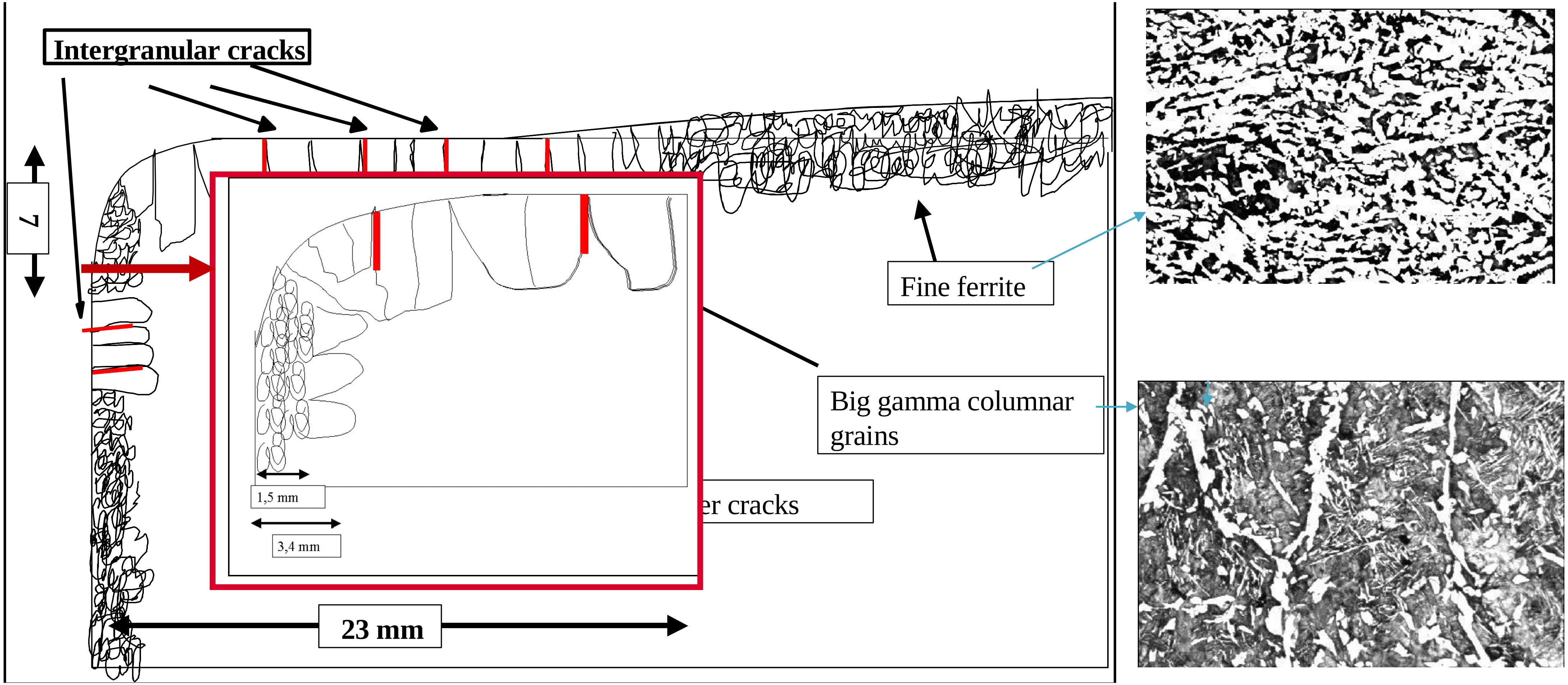
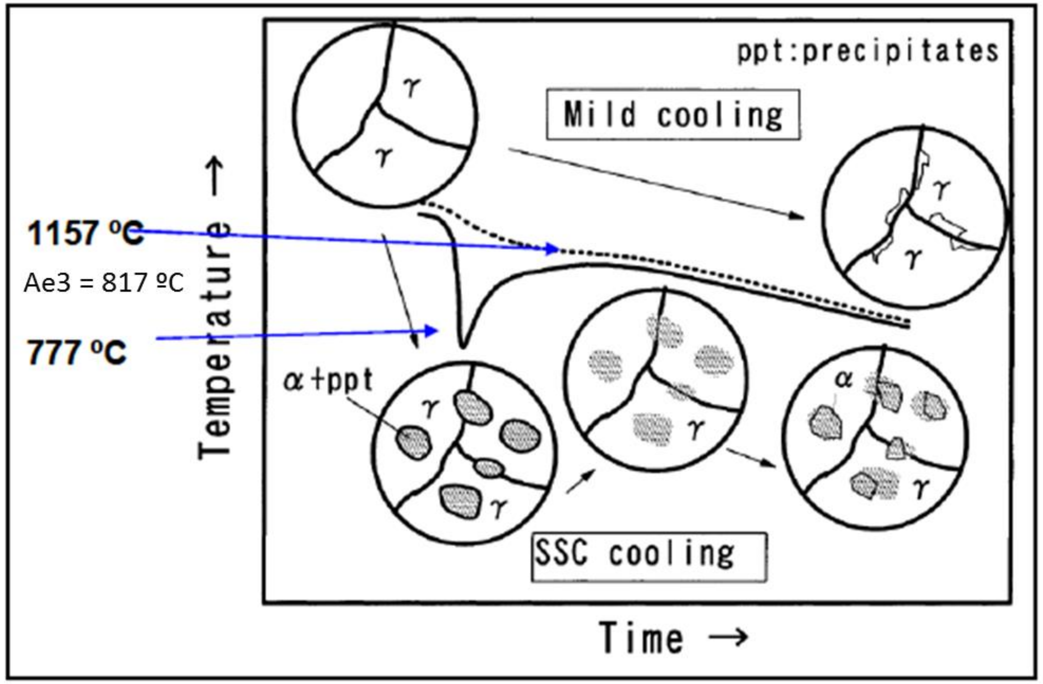
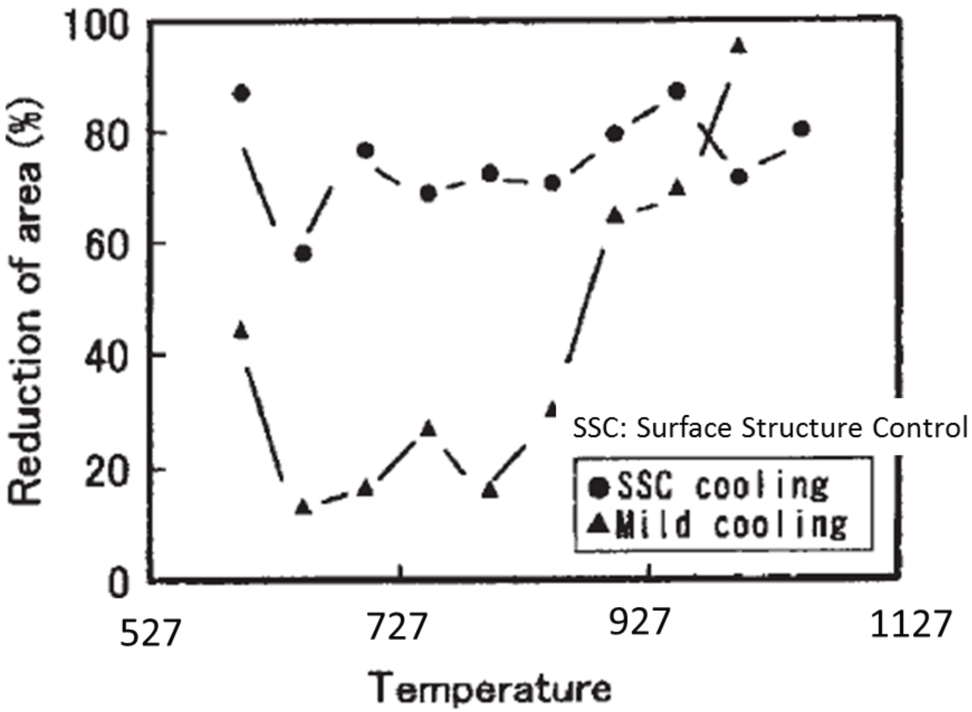


4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Watanabe et al. proposed an on-line temperature cycling to improve hot ductility





C	Si	Mn	Cu	Ni	Nb	Al	Ti	N
0.07	0.2	1.5	0.3	0.7	0.02	0.02	0.01	0.007

Watanabe et al. ISIJ International, 43, 2003, n.11, 1742.

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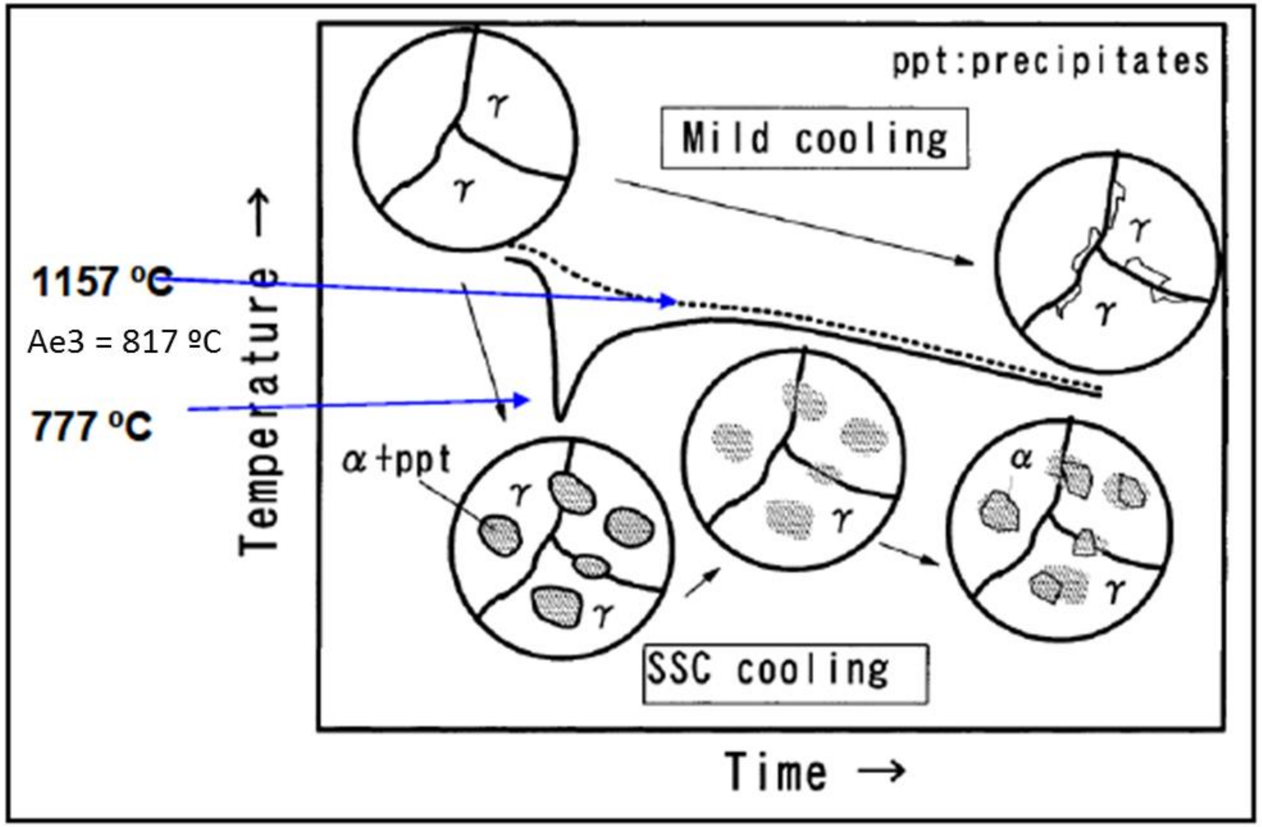
4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.



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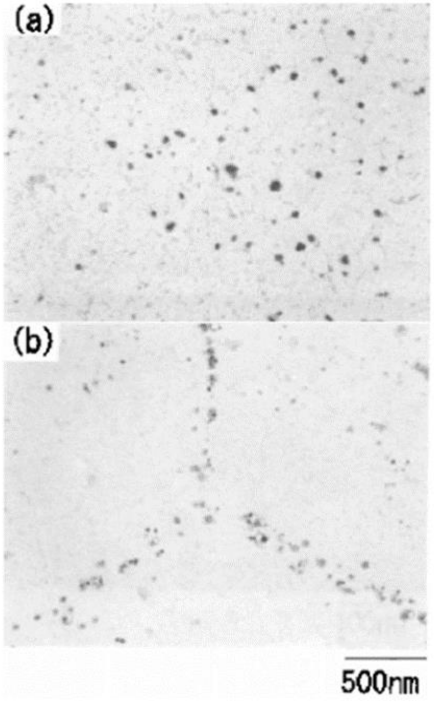

Differences on the precipitates distribution after:

a) On-line γ/α transformation, homogenous precipitation
b) Normal cooling: precipitation at the austenitic grain boundaries

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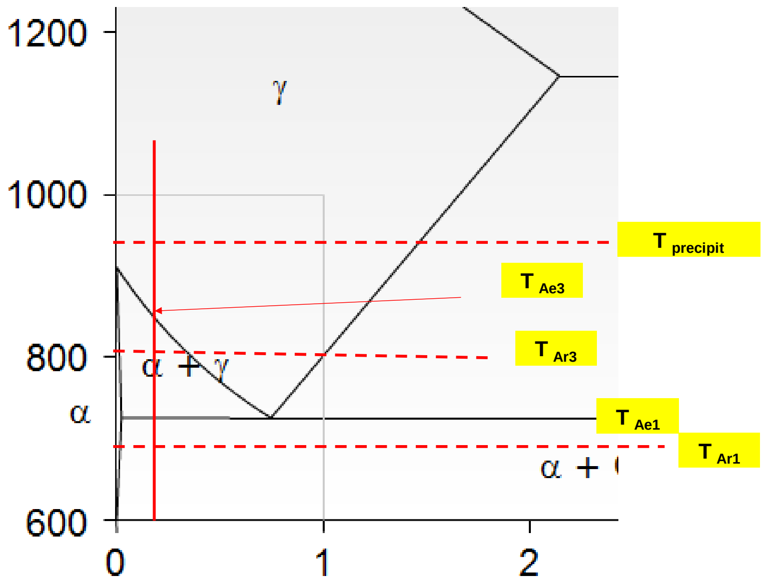
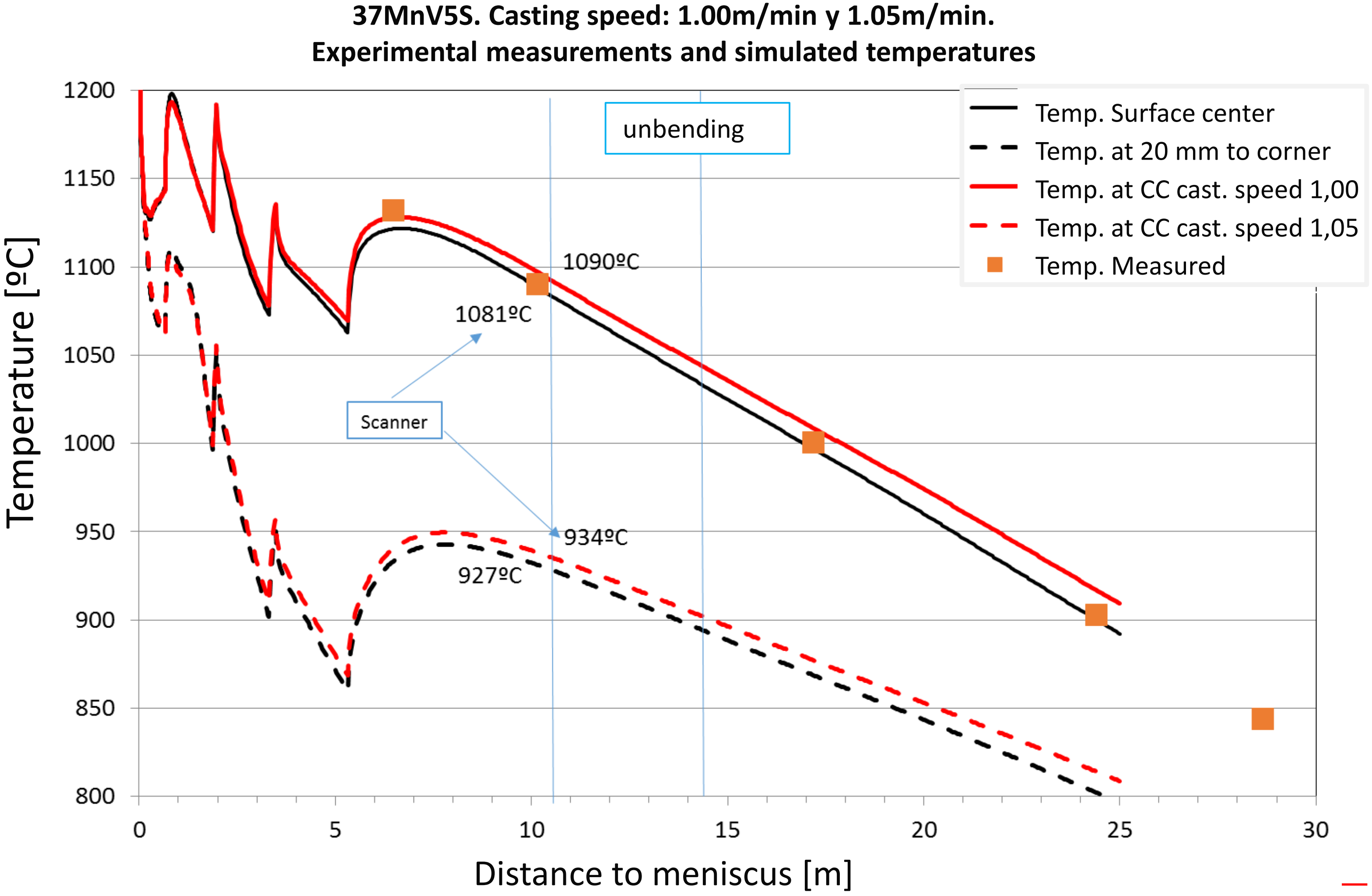
4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.





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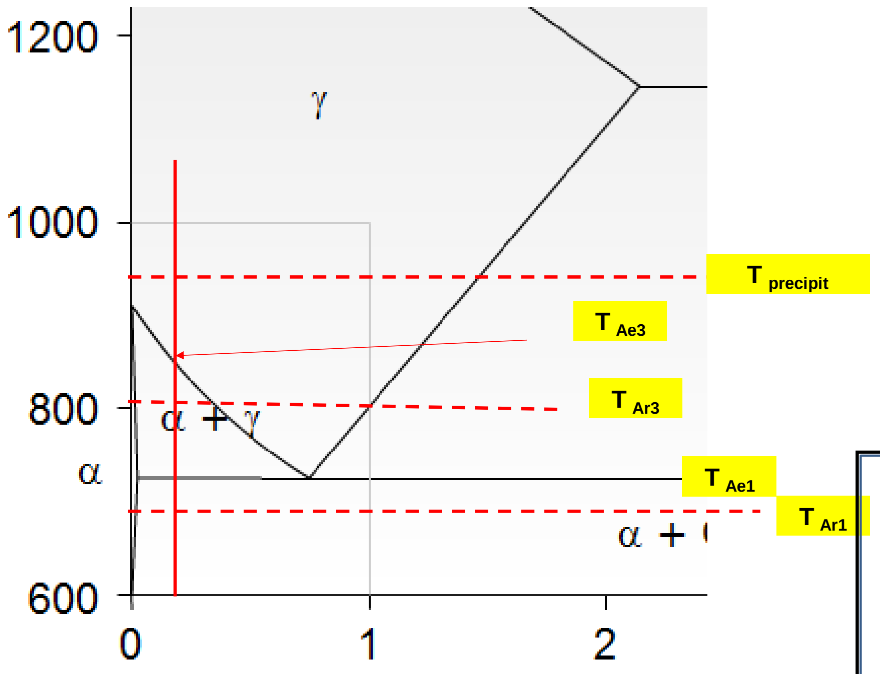
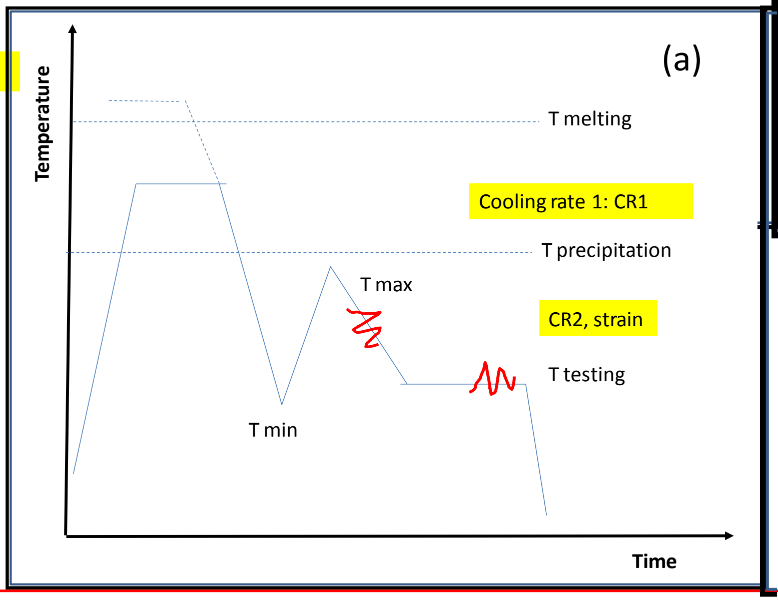
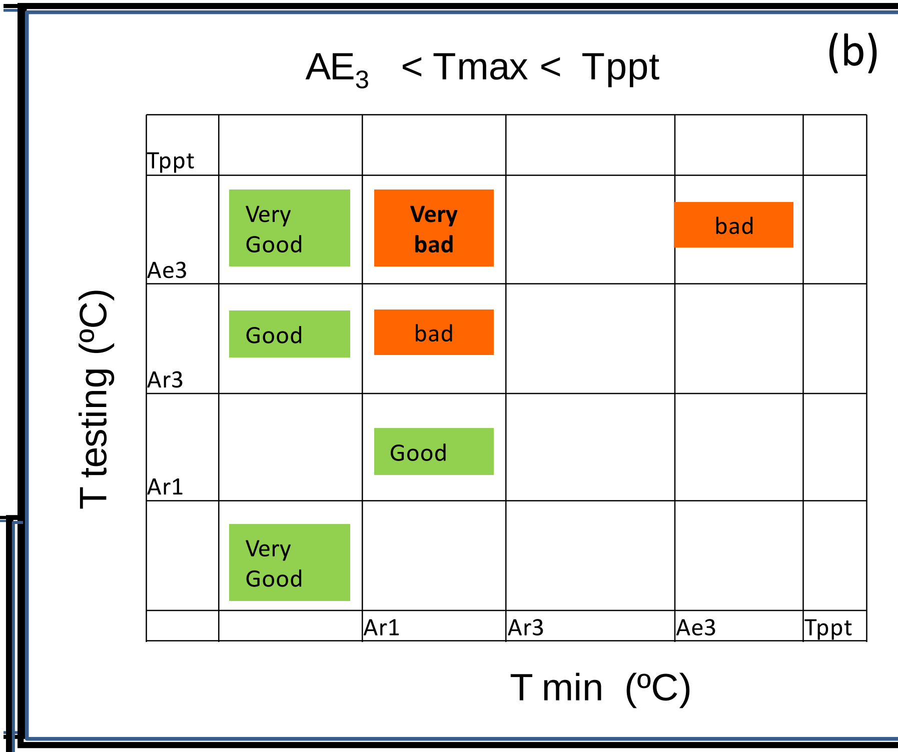
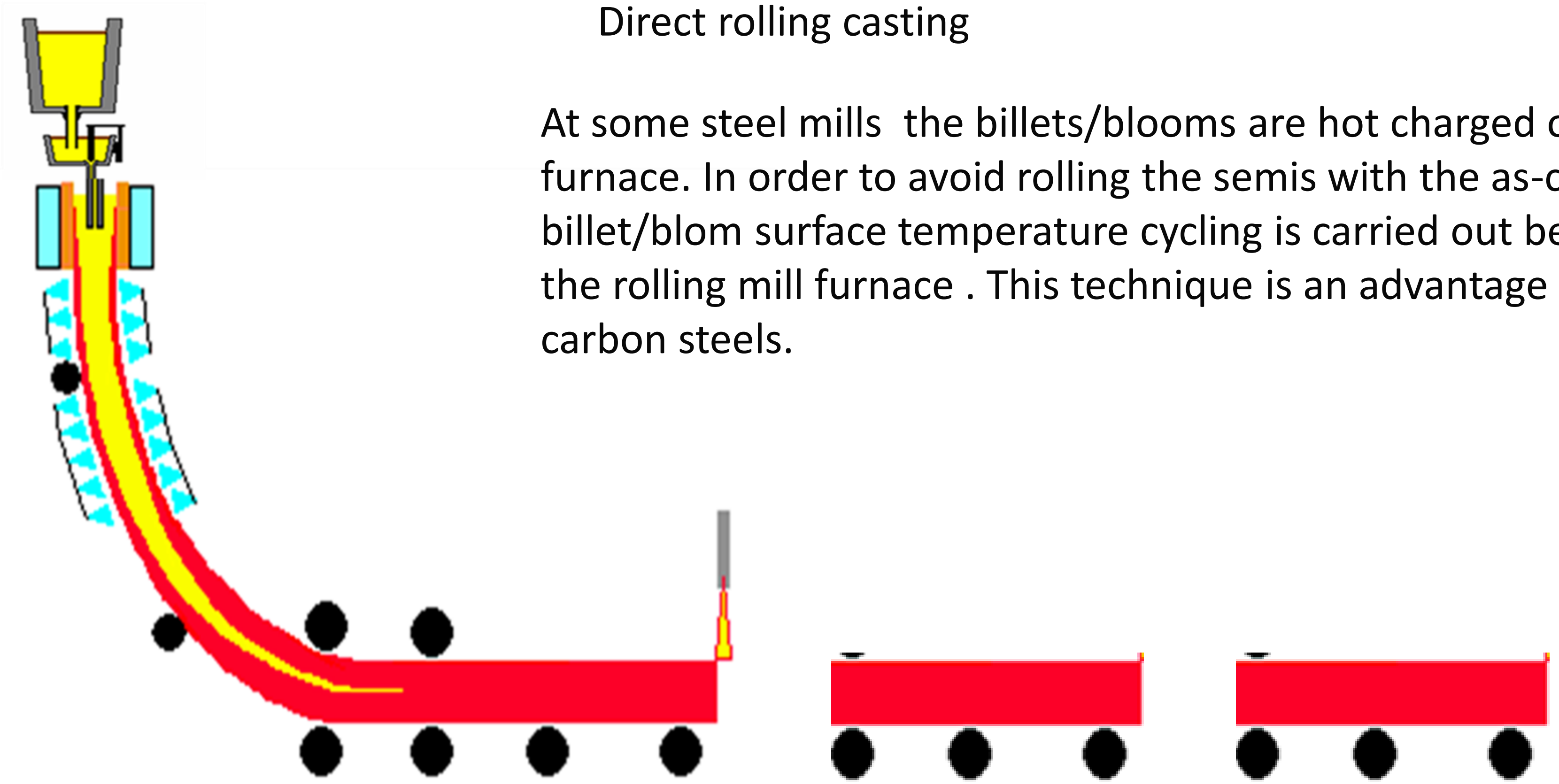






4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Industrial aplications:



Direct rolling casting

At some steel mills the billets/blooms are hot charged on the rolling furnace. In order to avoid rolling the semis with the as-cast structure a billet/blom surface temperature cycling is carried out before hot charging in the rolling mill furnace . This technique is an advantage when rolling low carbon steels.

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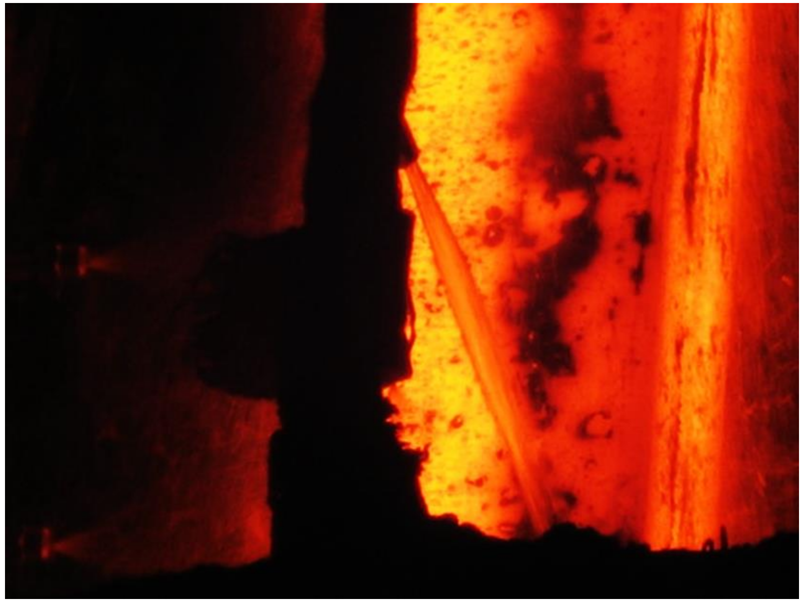
4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Secondary cooling influence

A heat of 37MnV5SF grade was cast with a secondary cooling problem. As a consequence of a malfunction of one nozzle located at the last row of the secondary cooling, a water jet impacted on the corner billet. At the exit of the secondary cooling the billet corner appeared black where the jet impacted.



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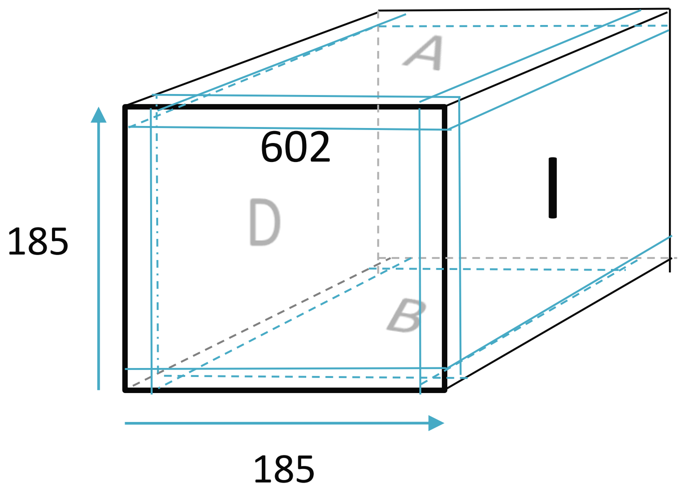
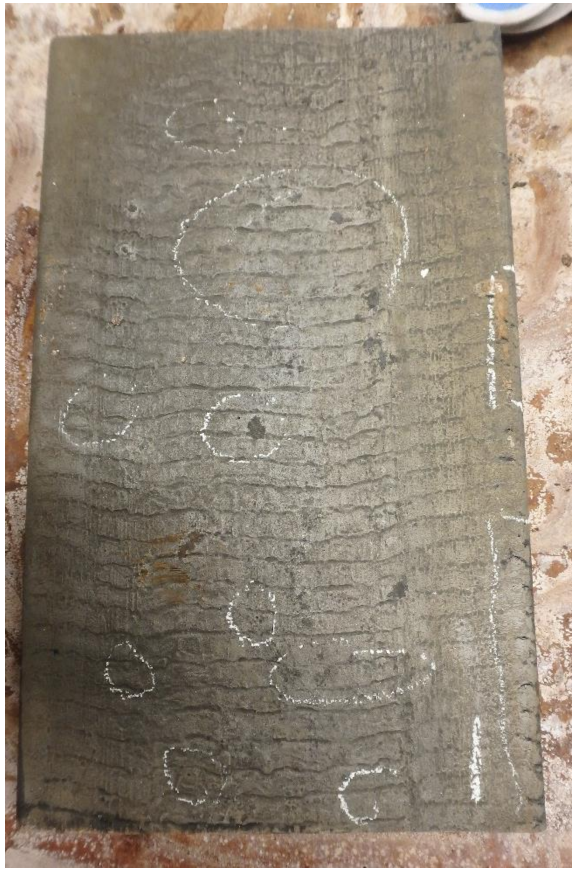
4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Secondary cooling influence

Longitudinal Surface (LS) samples were cut, in order to be able to relate the microstructure and the defects to each billet surface.



D



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4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Secondary cooling influence

Intergranular cracks on oscillation marks valleys, and on longitudinal channels: areas with large austenitic grain size

Transversal cracks on oscilation marks.

The area where the jet impacted present intergranular and transversal cracks.
The other corners don´t present these defects.

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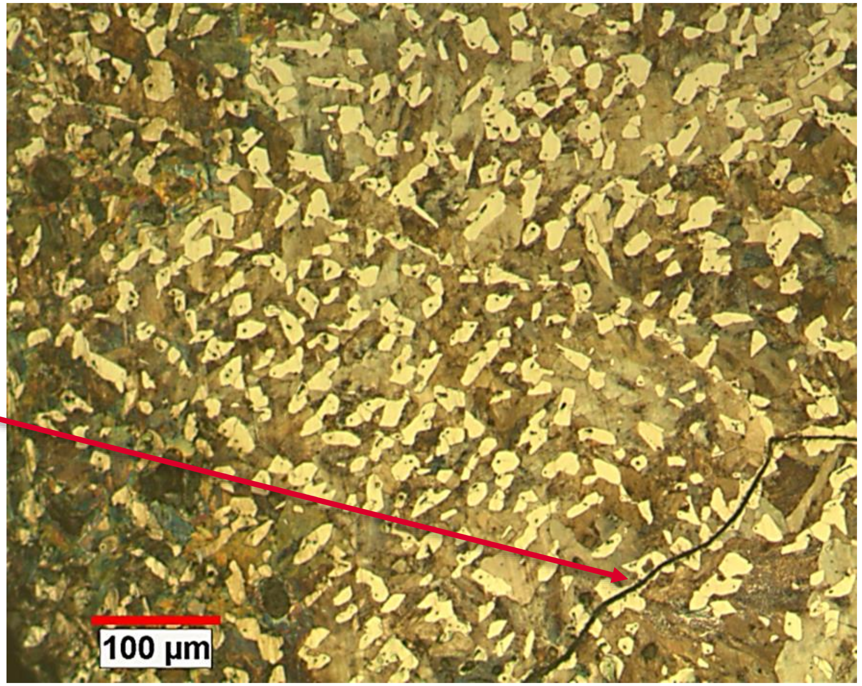
4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Secondary cooling influence

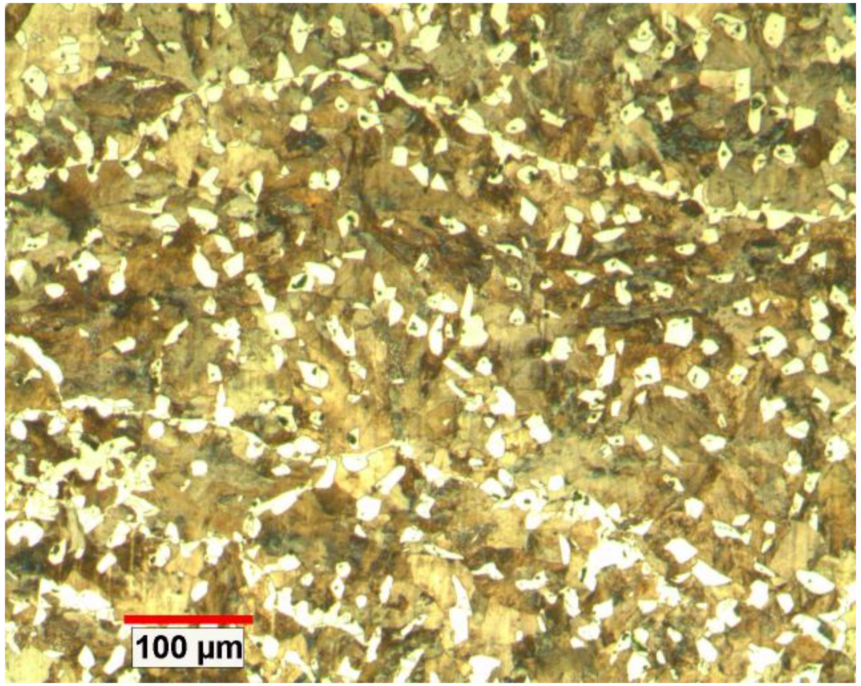
Cracked corner

Intergranular Crack at an oscillation mark



- Ferrite content: 11.6%,
- Ferrite average size: 135.6 µm^2
- Surface distance 1 mm.
- Ferrite grains nucleate at precipitates

Non-Cracked corner



- Ferrite content: 10,9%
- Ferrite average size: 49,6 µm^2
- Surface distance 1 mm.

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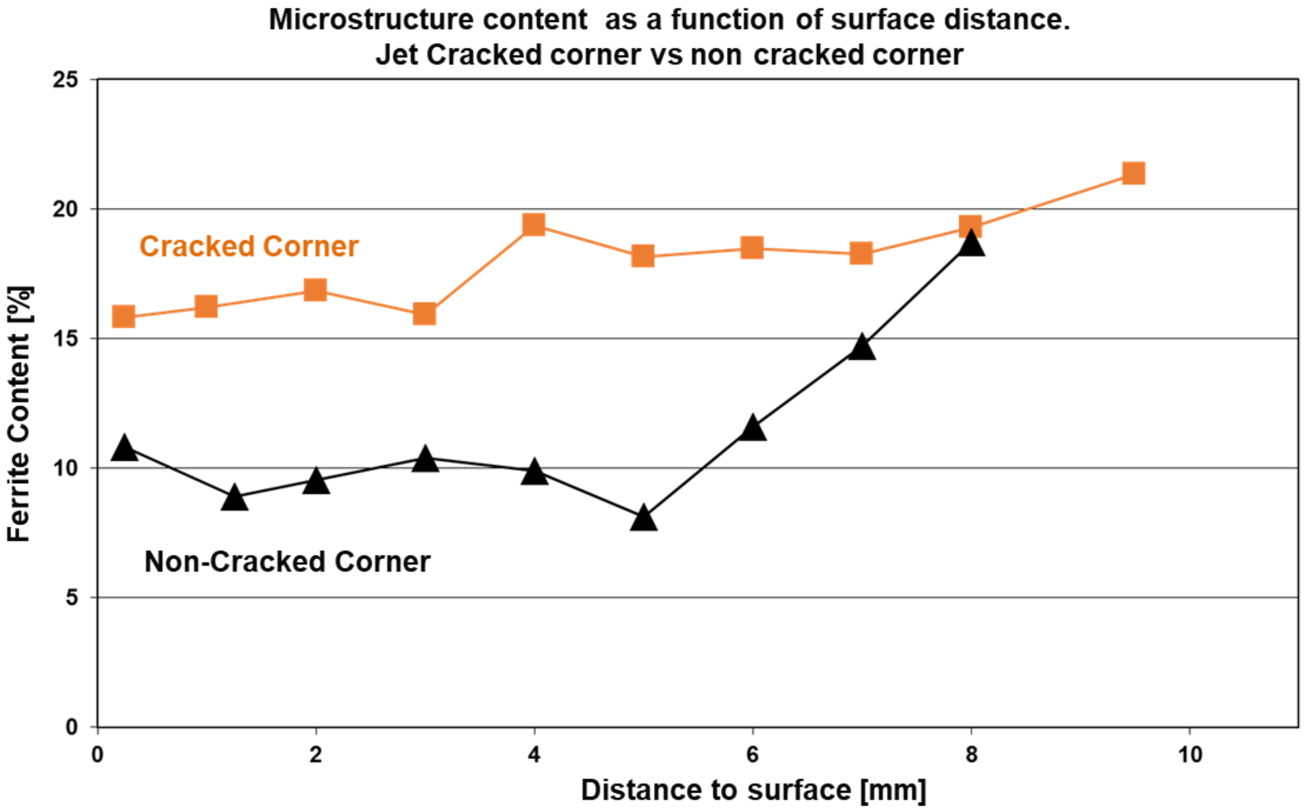
4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Secondary cooling influence

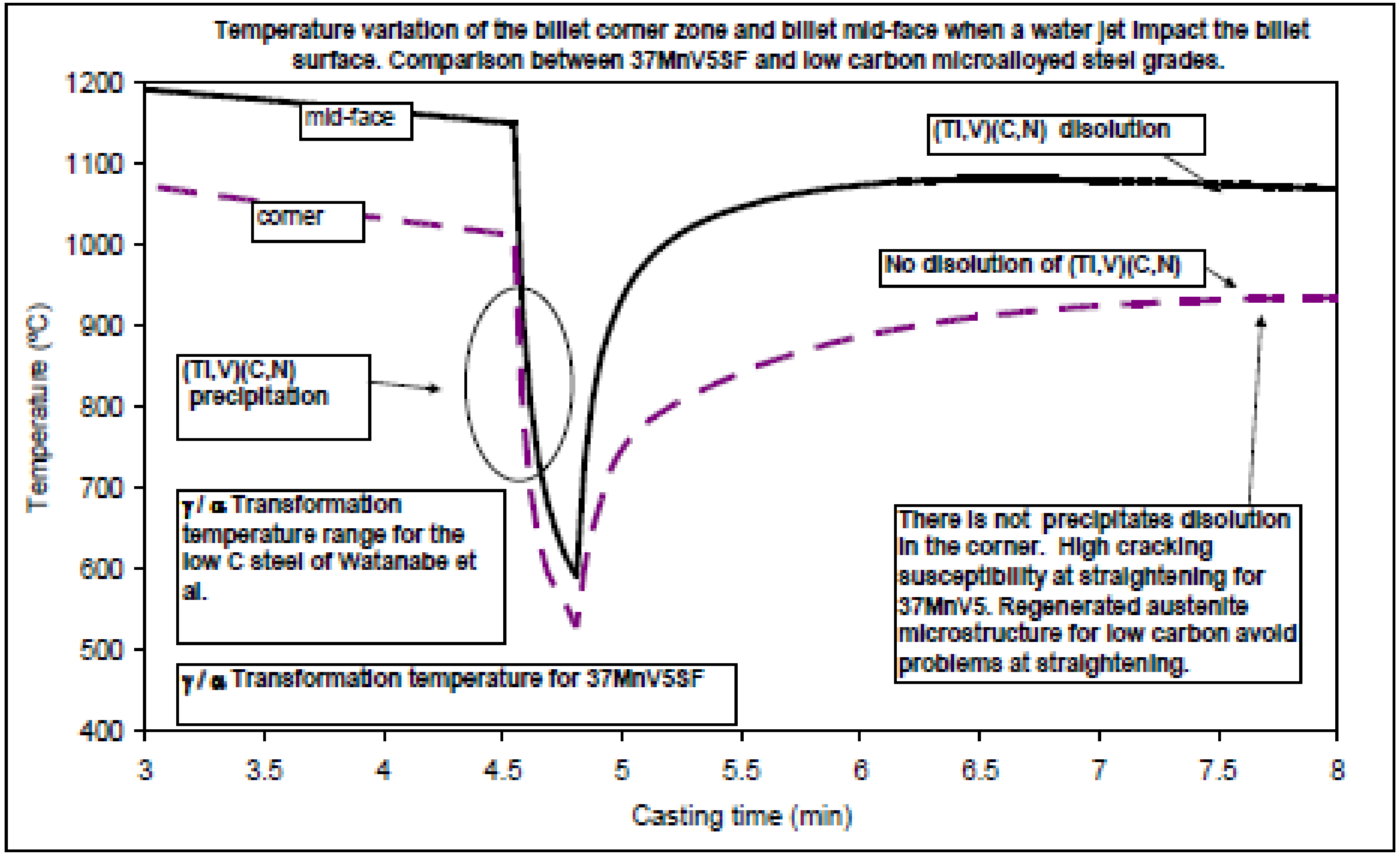
- The area were the jet impacted presents intergranular cracks.
- Influence of the jet on the microstructure: the corner has a 50% more of ferrite at the surface.
- The ferrite nucleated on prior precipitated particles, mainly MnS, which were favored by the cooling of the jet impact.



4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

Secondary cooling influence

- Due to the high cooling rate, the g/a transformation start temperature lowers to around 490 ºC
- No γ/α transformation takes place during the jet impact at the area near the corners of the billet.
- During the heat recovery, (Ti,V)(C,N) precipitates are dissolved in the mid face but not in the billet corner.



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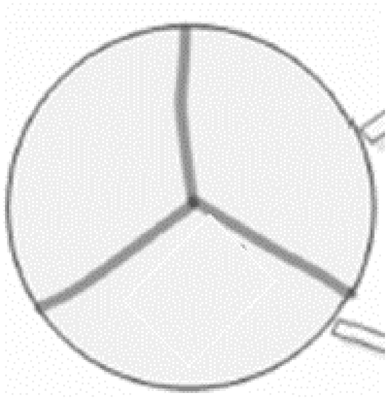
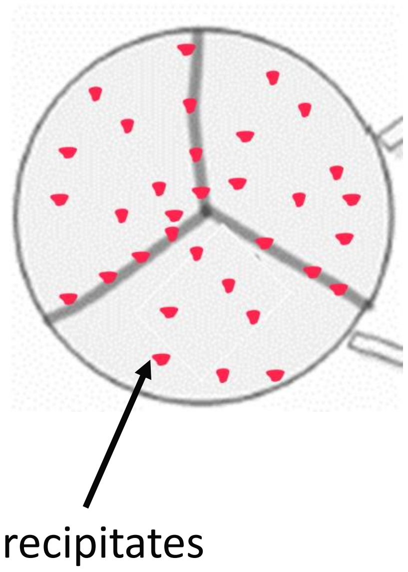
4. Methods to avoid intergranular cracking: On-line double γ/α transformation and secondary cooling influence.

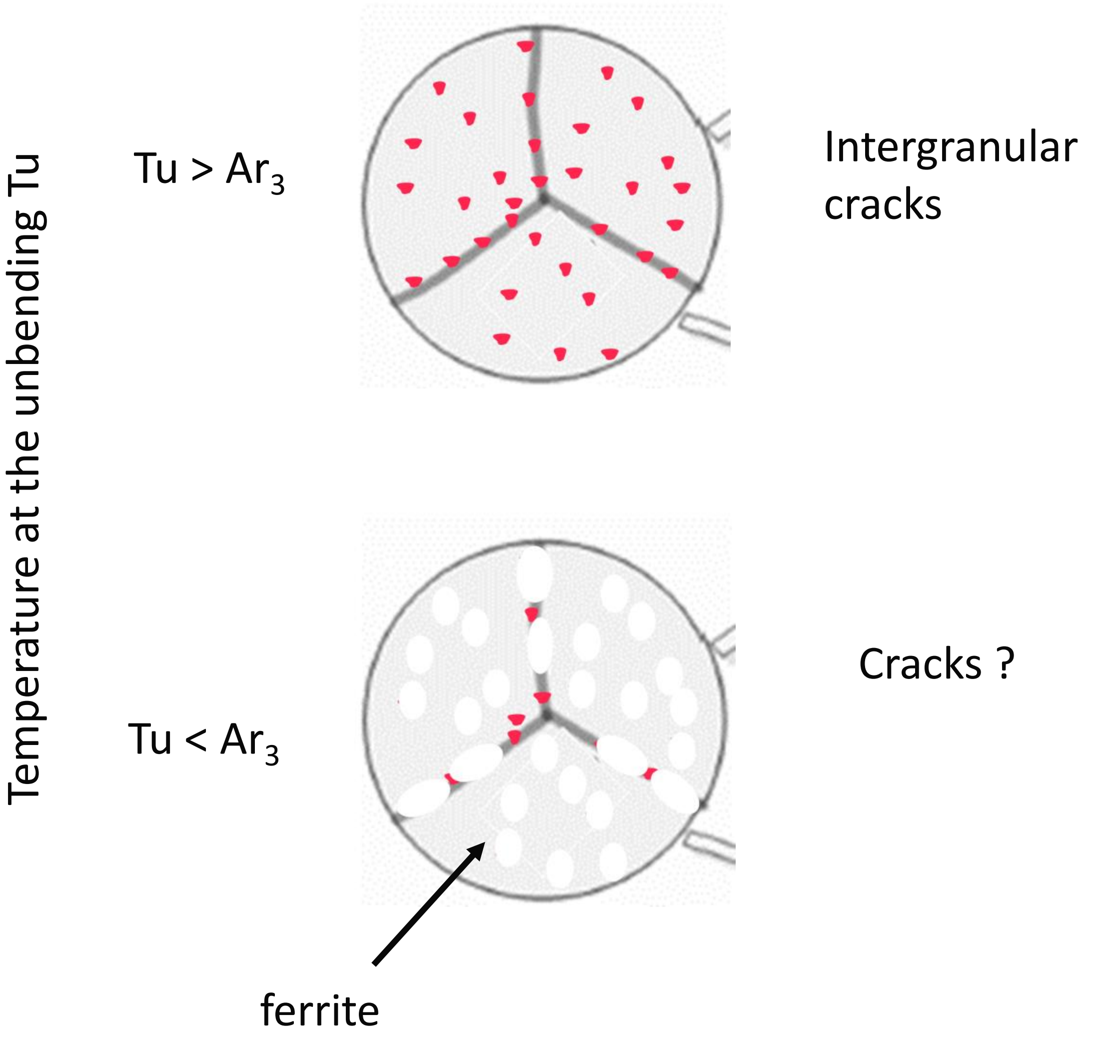
Secondary cooling influence

Before the jet impact



After the jet impact





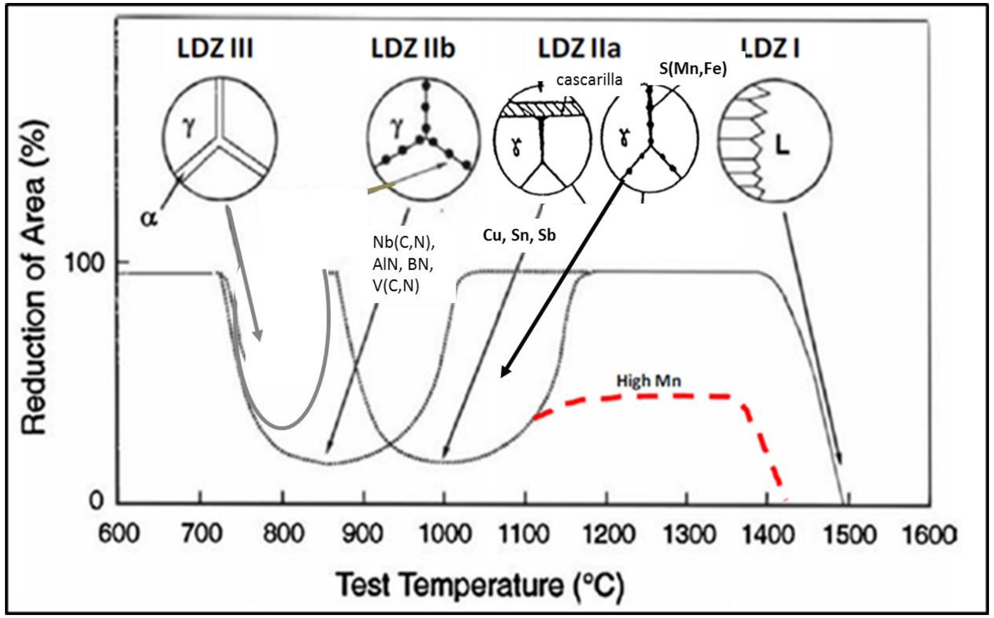
When the secondary cooling of the continuous casting machine is not working properly, an event similar to the previous presented problem for the 37MnV5SF heat may take place.

5. CONCLUSIONS

5. Conclusions

The best tips to avoid intergranular cracks are:

1. Avoid semis reheatings and stresses inside the mould.
2. Ensure a higher temperature along the strand until the un-bending than the precipitation temperature.
3. Reach the un-bending at a lower temperature than the γ / α transformation. “cold casting”
4. Perform an on-line temperature cycling.
5. Ensure a propter performance of the secondary cooling.



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