Surface cracks on Continuous Casting Billets

INFLUENCE OF COMPOSITION AND CASTING PARAMETERS ON THE CRACKING OF CONTINUOUSLY CAST BILLETS

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Process Department

Sidenor I+D

European Commission

Research Fund for Coal & Steel

2. Surface cracks on Continuous Casting Billets

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1. Introduction

1. Introduction

Surface cracks

Surface defects:

Transversal cracks

Intergranular 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.

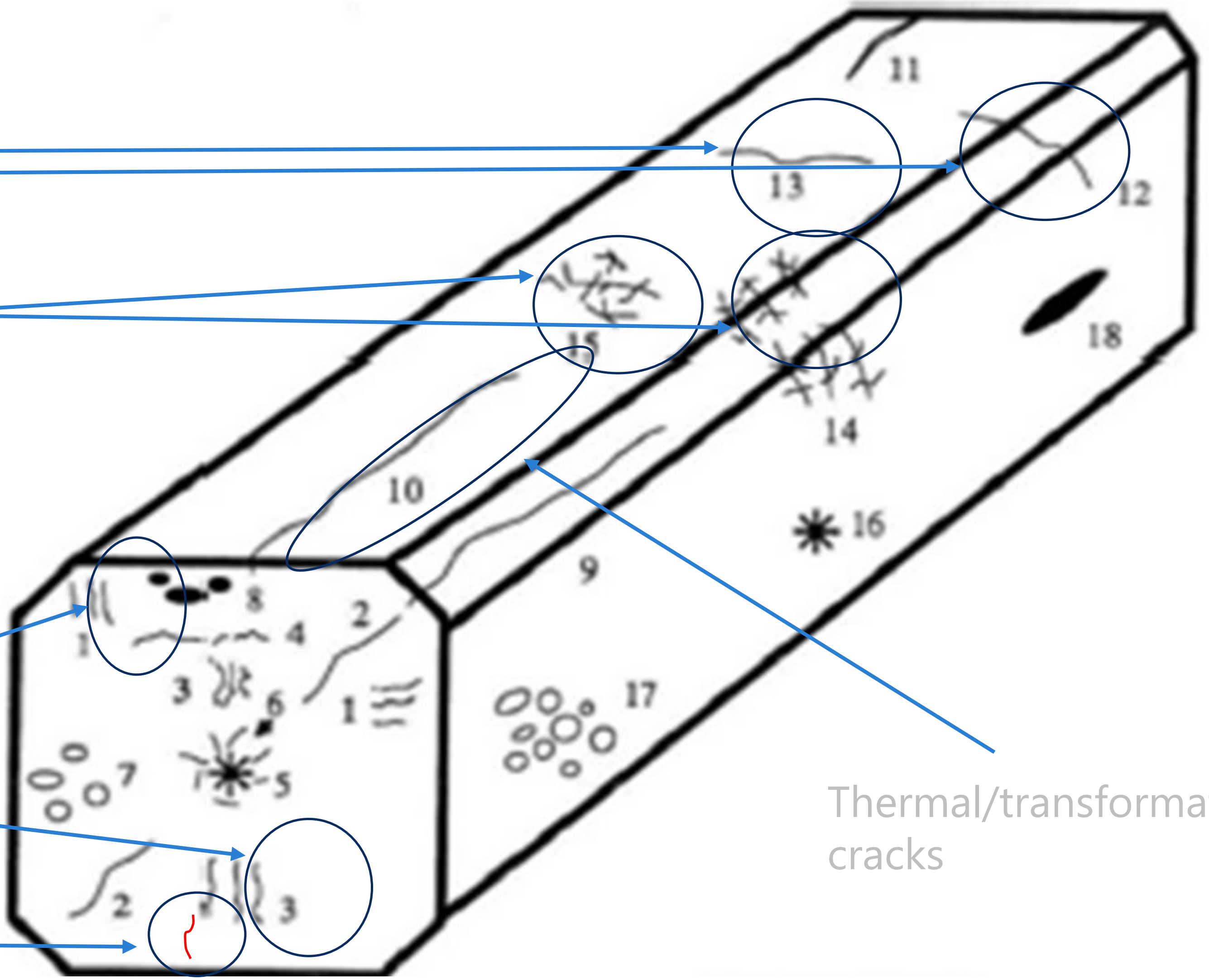
Internal segregation cracks

Off-corner cracks

Half-way cracks

Near corner cracks

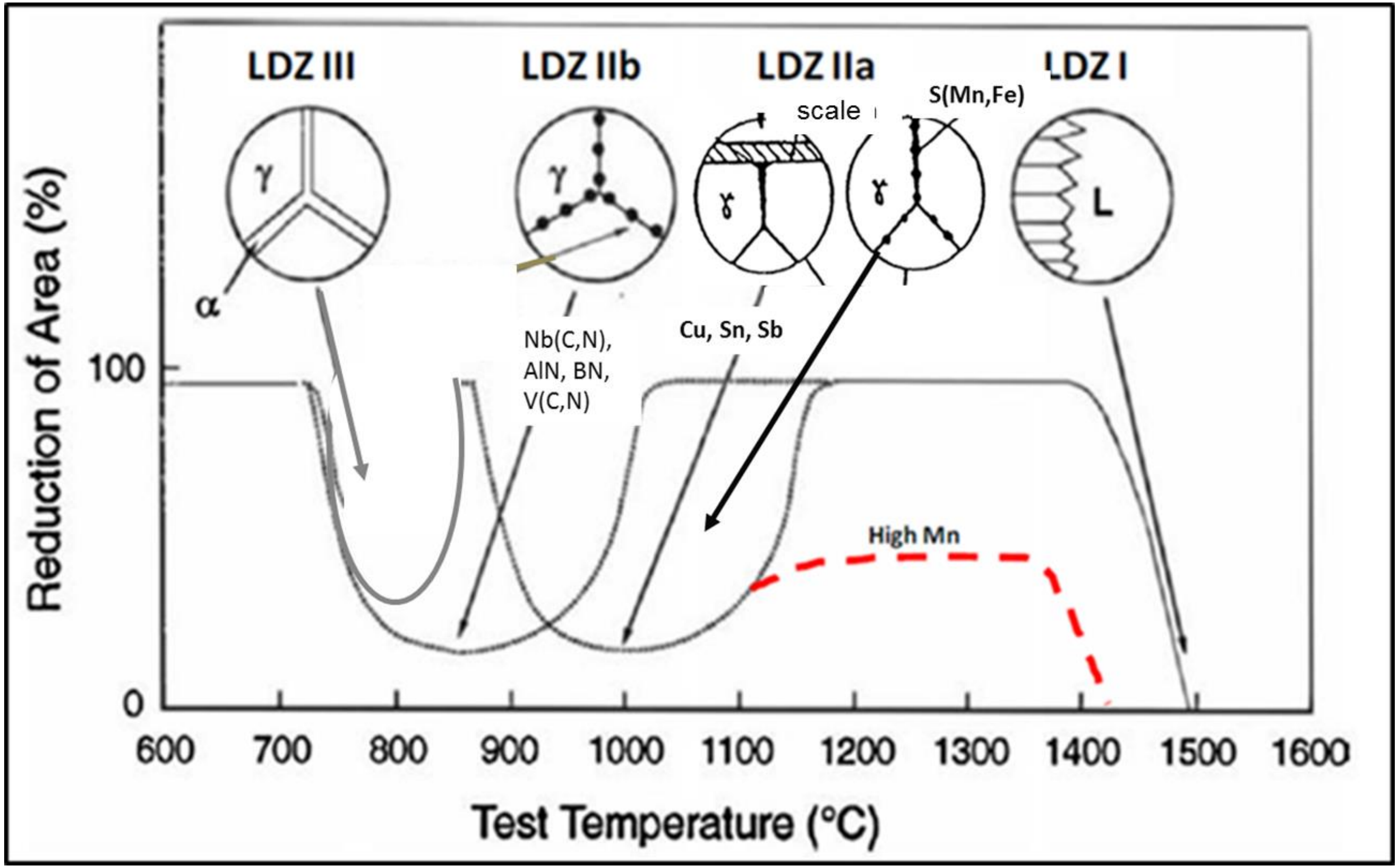
Thermal/transformation cracks



1. Introduction

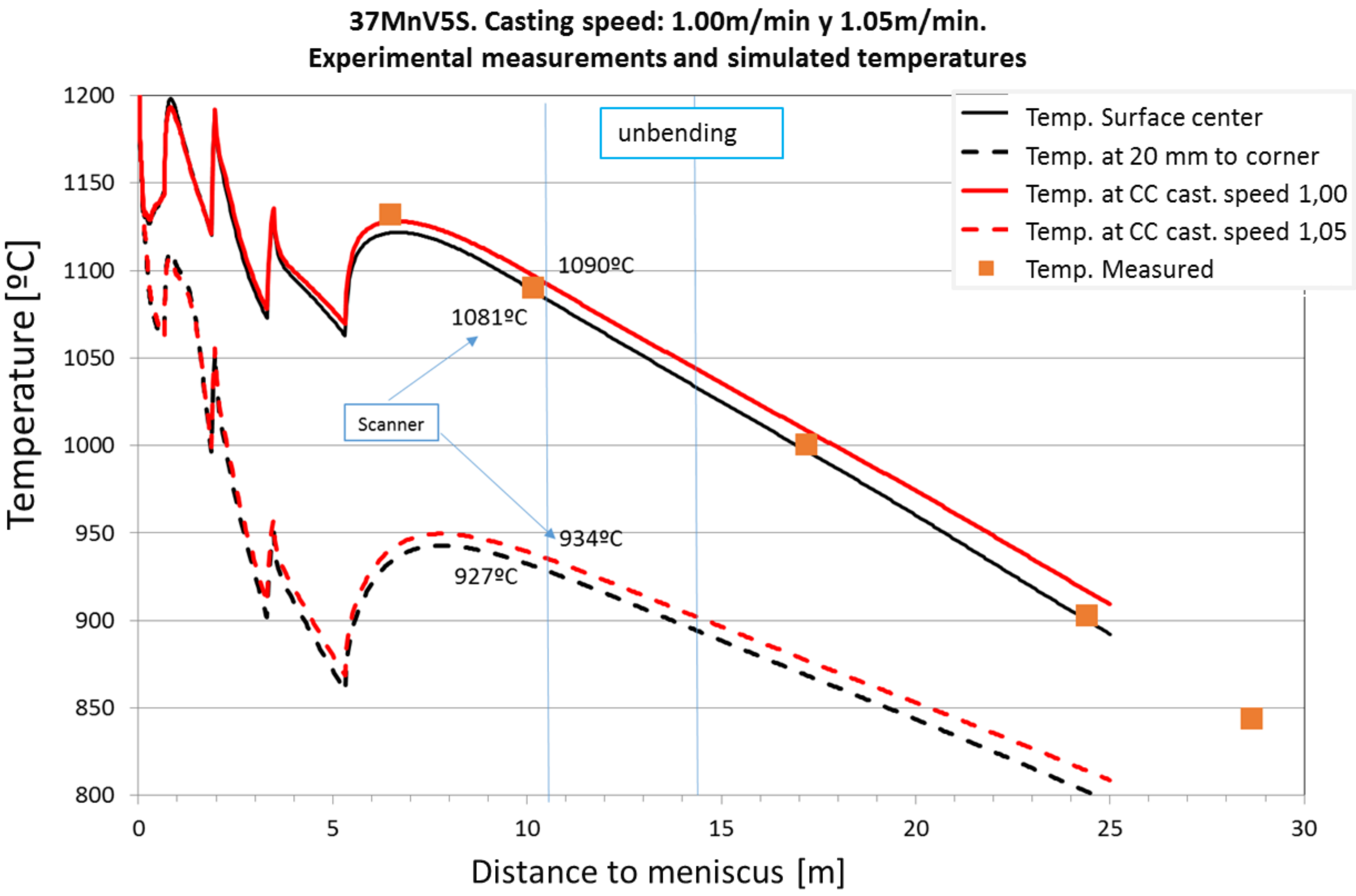
High temperature ductility troughs

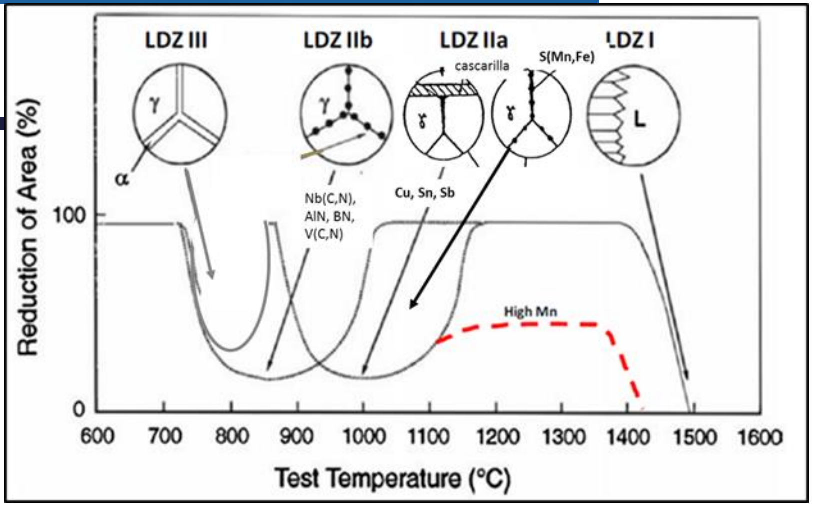
High temperature low ductility zones (LDZ) during solidification and cooling of the CC billet

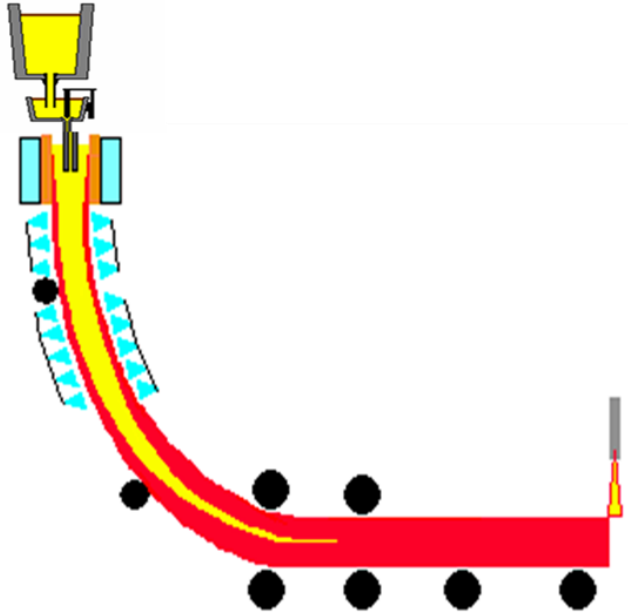


1. Introduction

Temperature evolution during continuous casting

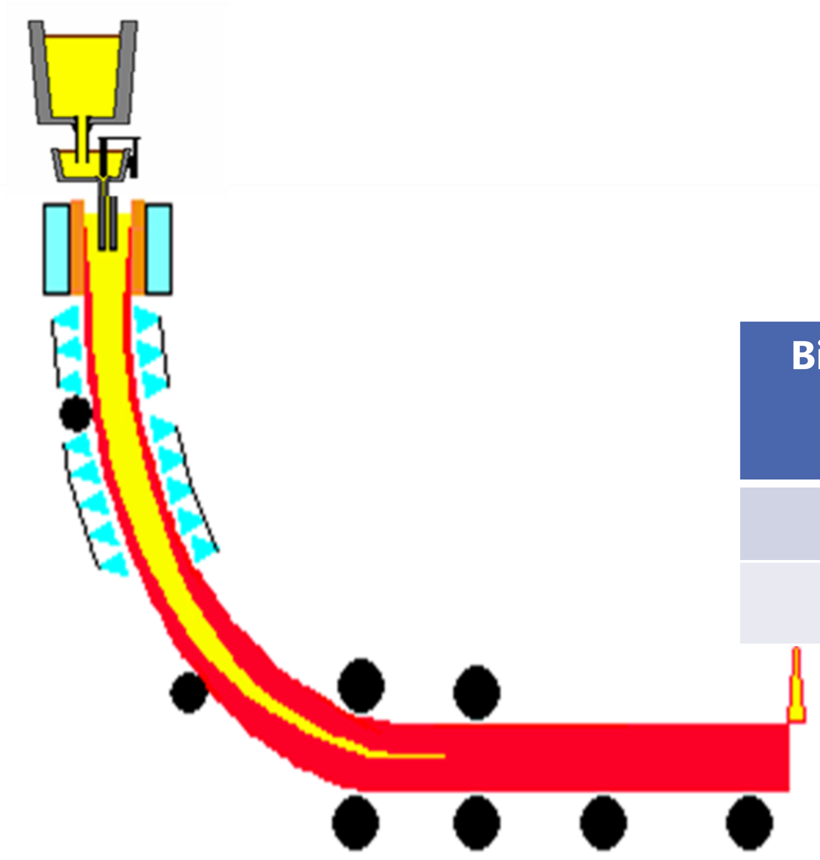






1. Introduction

Strains at the continuous casting



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

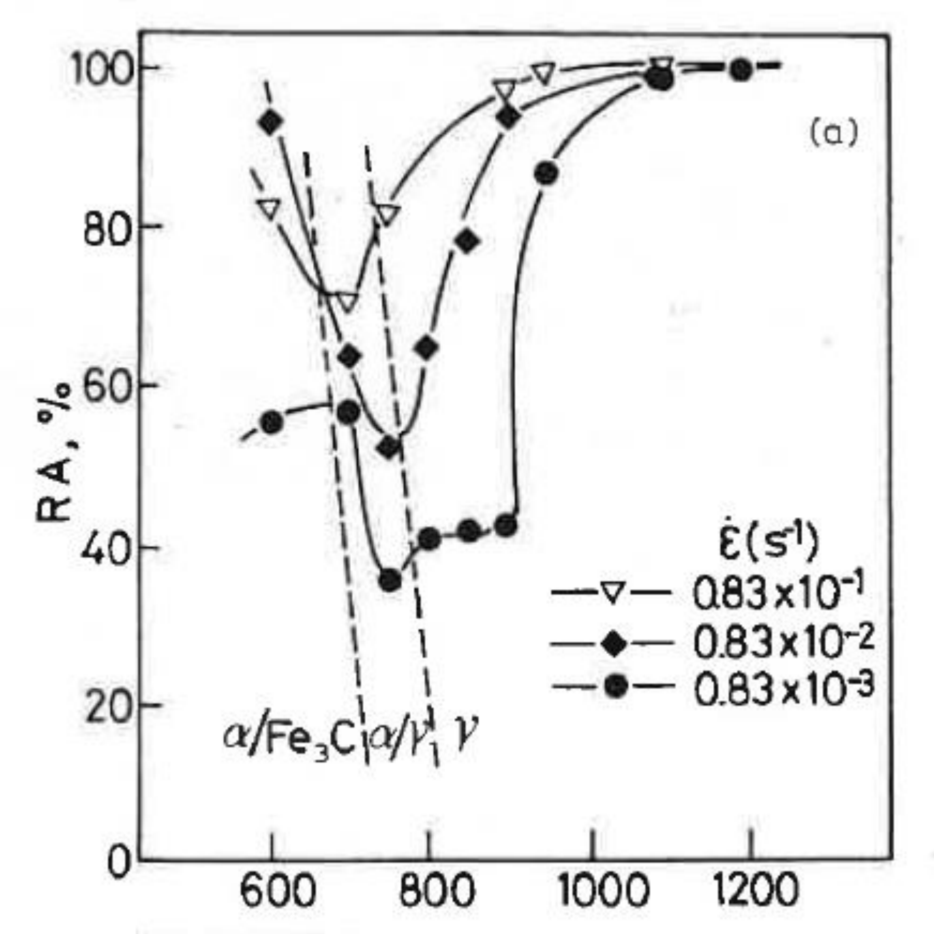
Strains at the unbending as a function of the number of radii

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%

1. Introduction

Influence of strain rate on ductility trough



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

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

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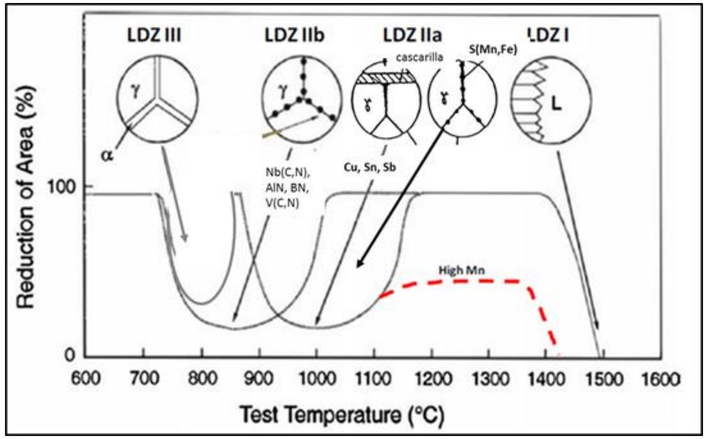
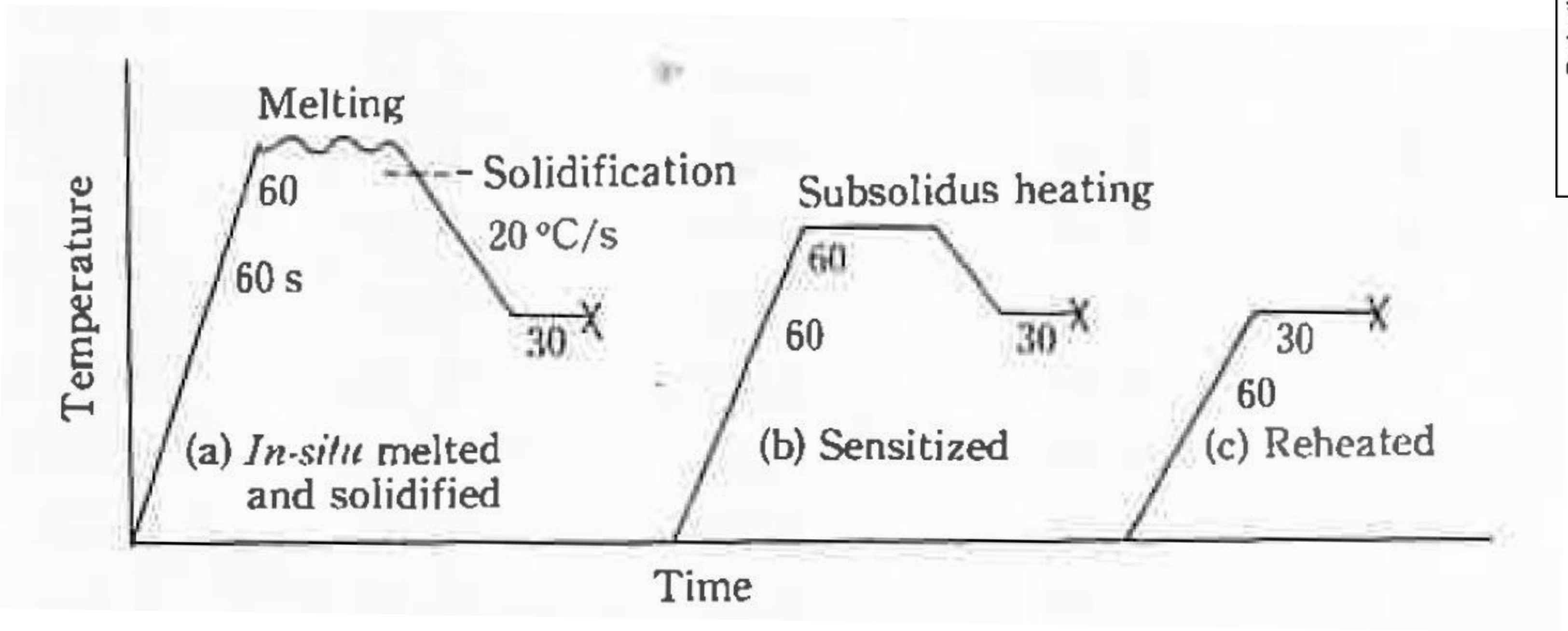
Continuous Casting Machine design criteria: Increase the casting radius or the number of radius at the unbending in order to obtain a strain lower than 1%

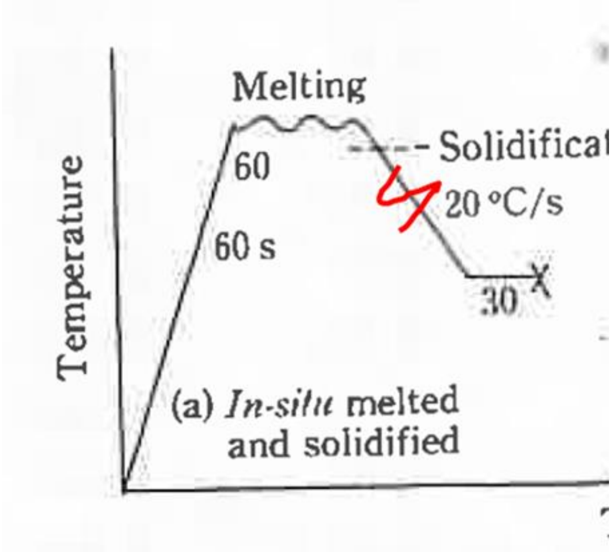
As the strain rate decreases so it does the Reduction of Area. Strain rates at CC in the range: 10^{-3} - 10^{-4} seg^{-1}

1. Introduction

Hot ductility laboratory characterization







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

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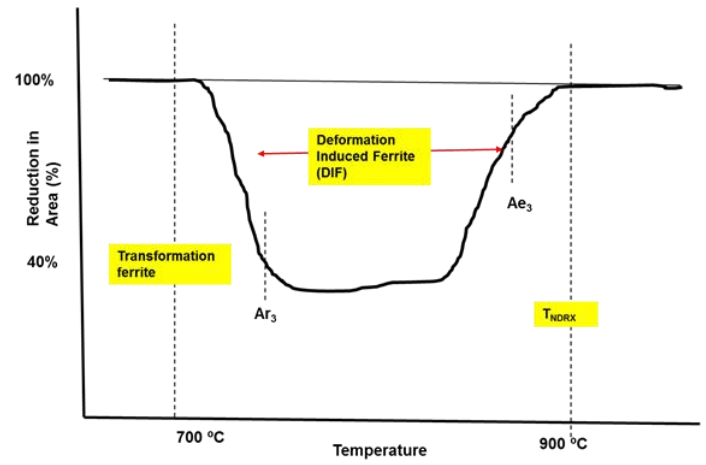
Low ductility trough for steel tested at low strain rates. (plain C-Mn steels)



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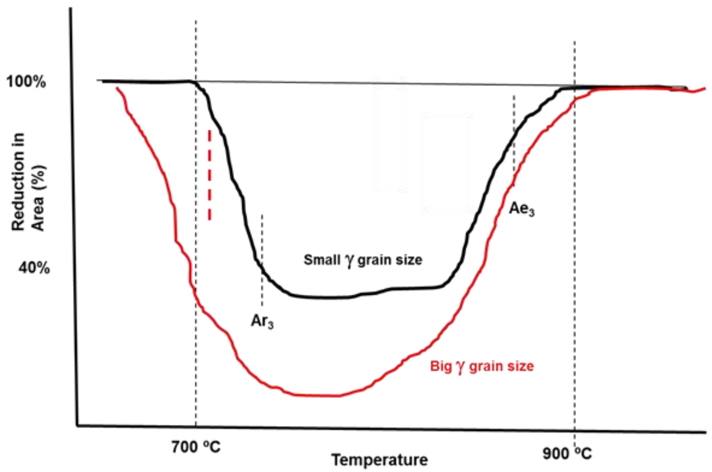
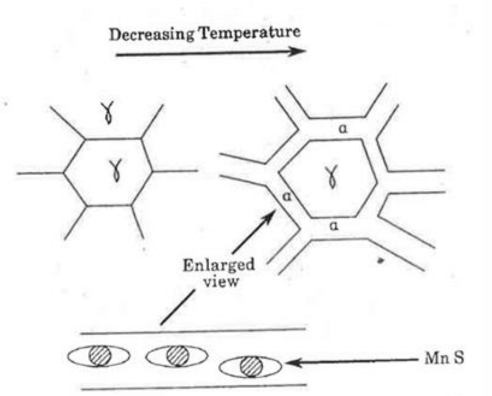
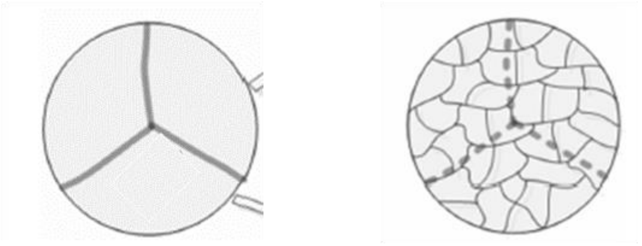




6 Schematic diagram showing mechanism for transformation induced intergranular failure

Austenitic Grain size



Big

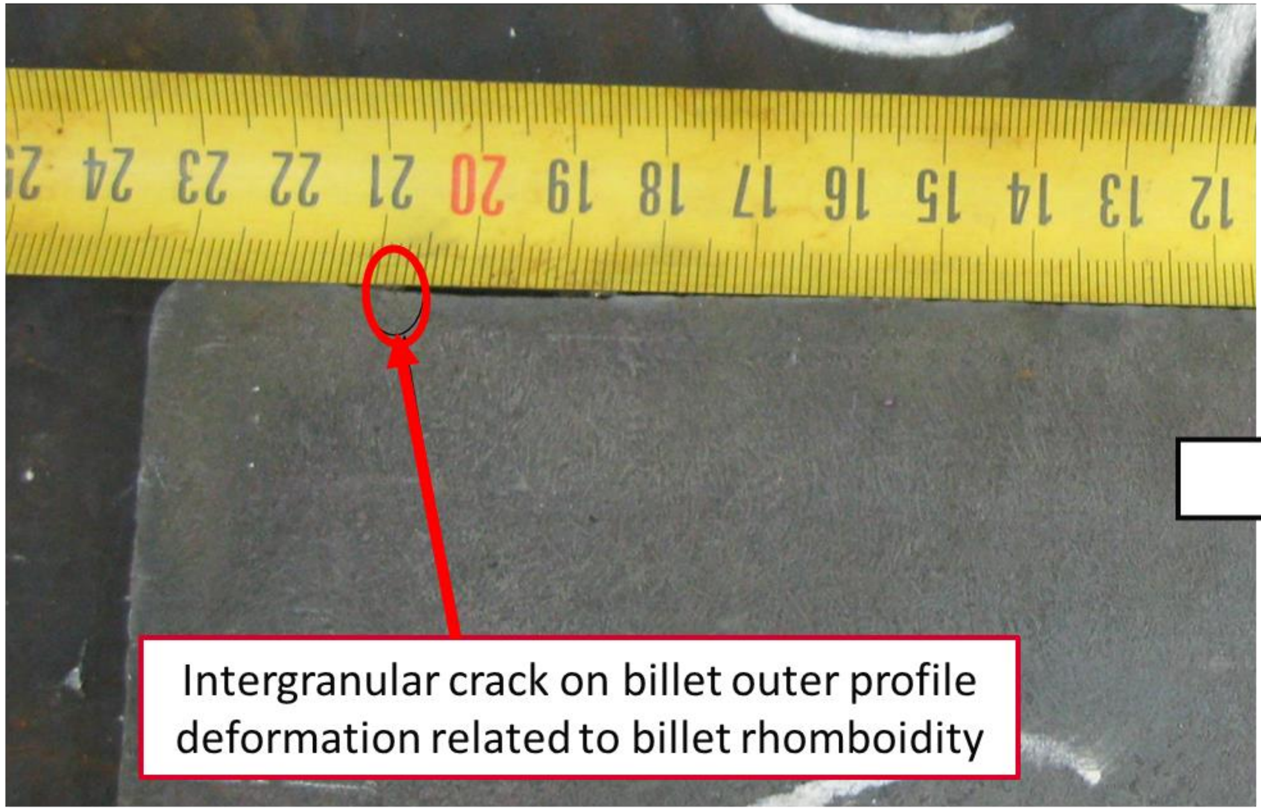
Small

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

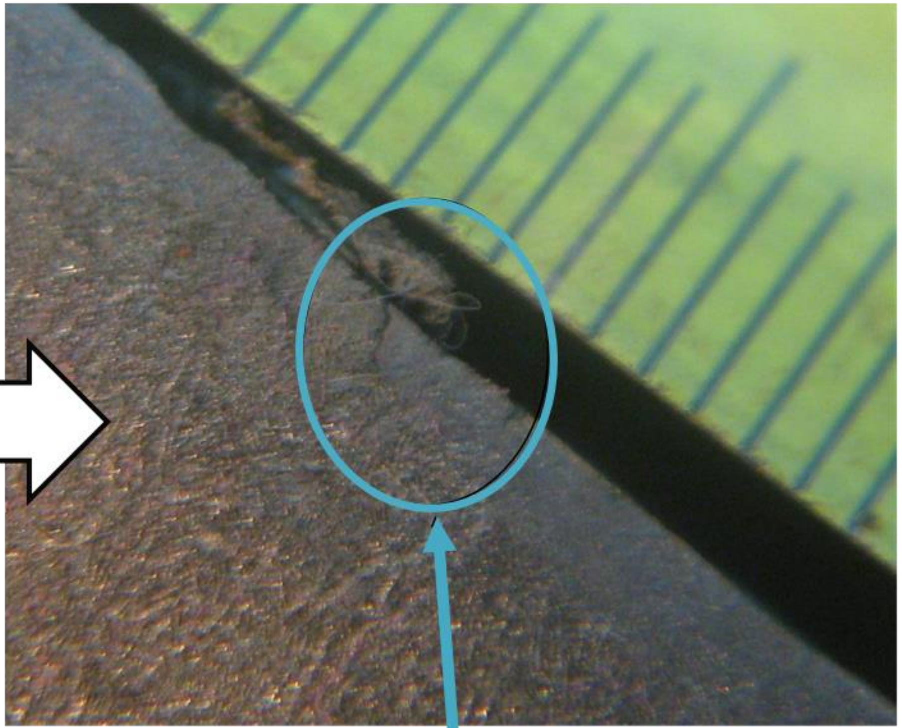
- Billet corner, 19MnNbV5C steel grade.
  Hot acid etching

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

37MnV6S Billet transversal slice



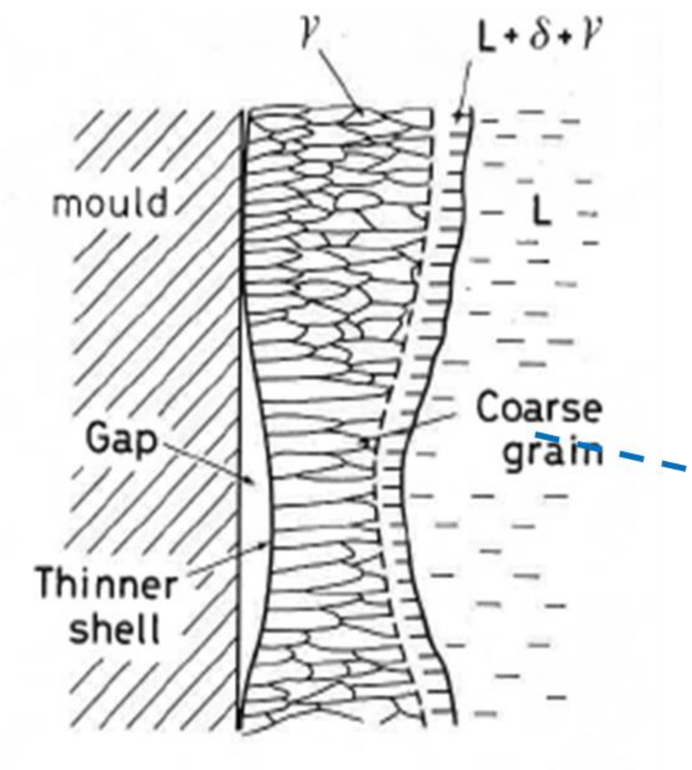
Intergranular crack on billet outer profile deformation related to billet rhomboidity



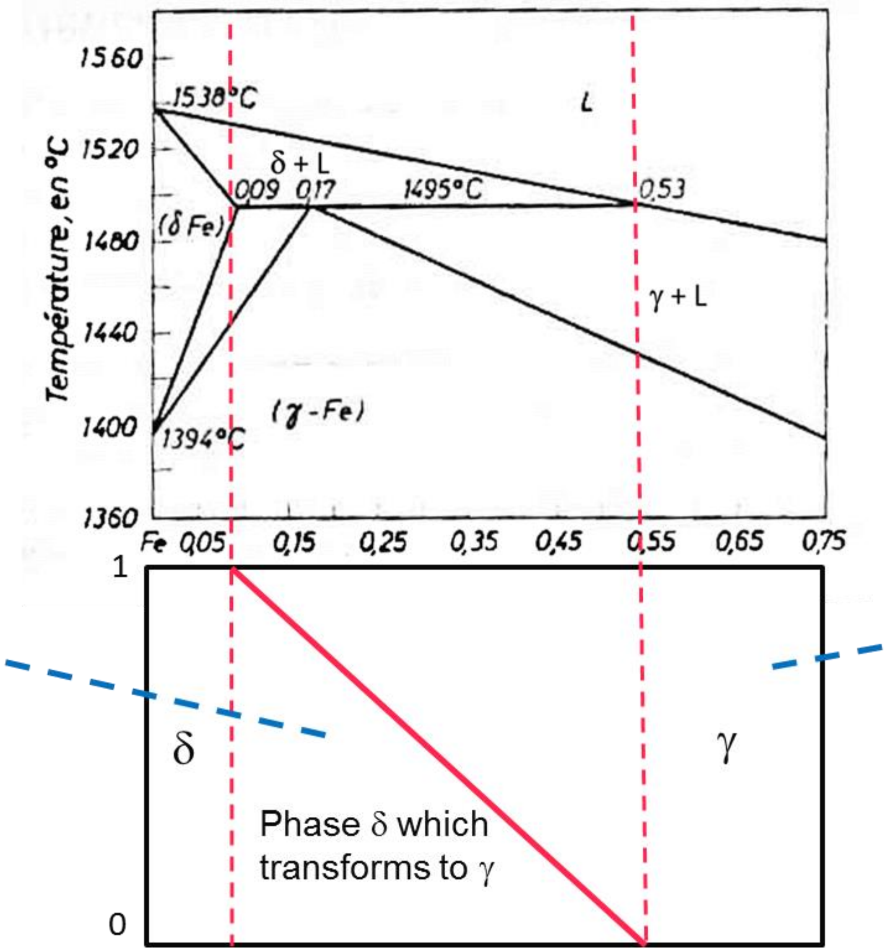
Intergranular crack depth: 2mm

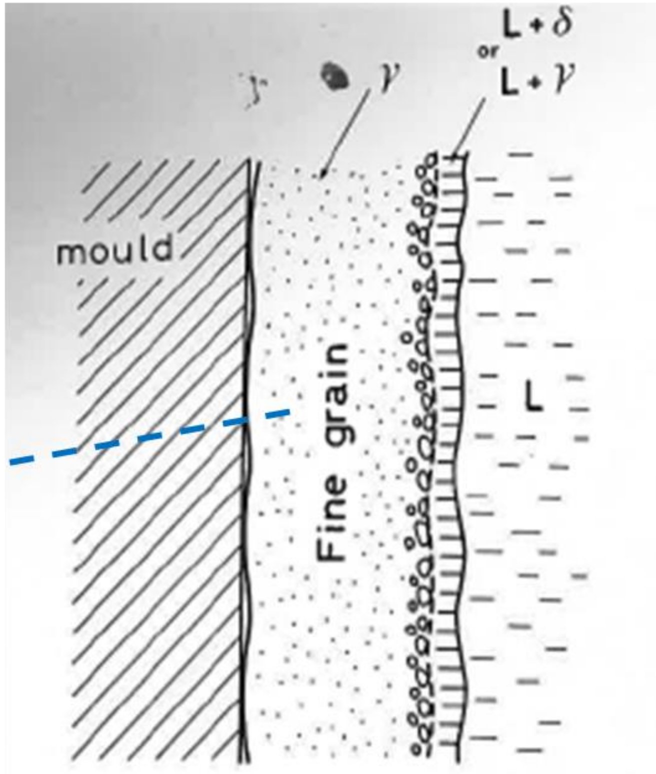
2. Influence of the γ/α transformation and of the austenitic grain size on cracking

Steel composition influence on austenitic grain size:



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





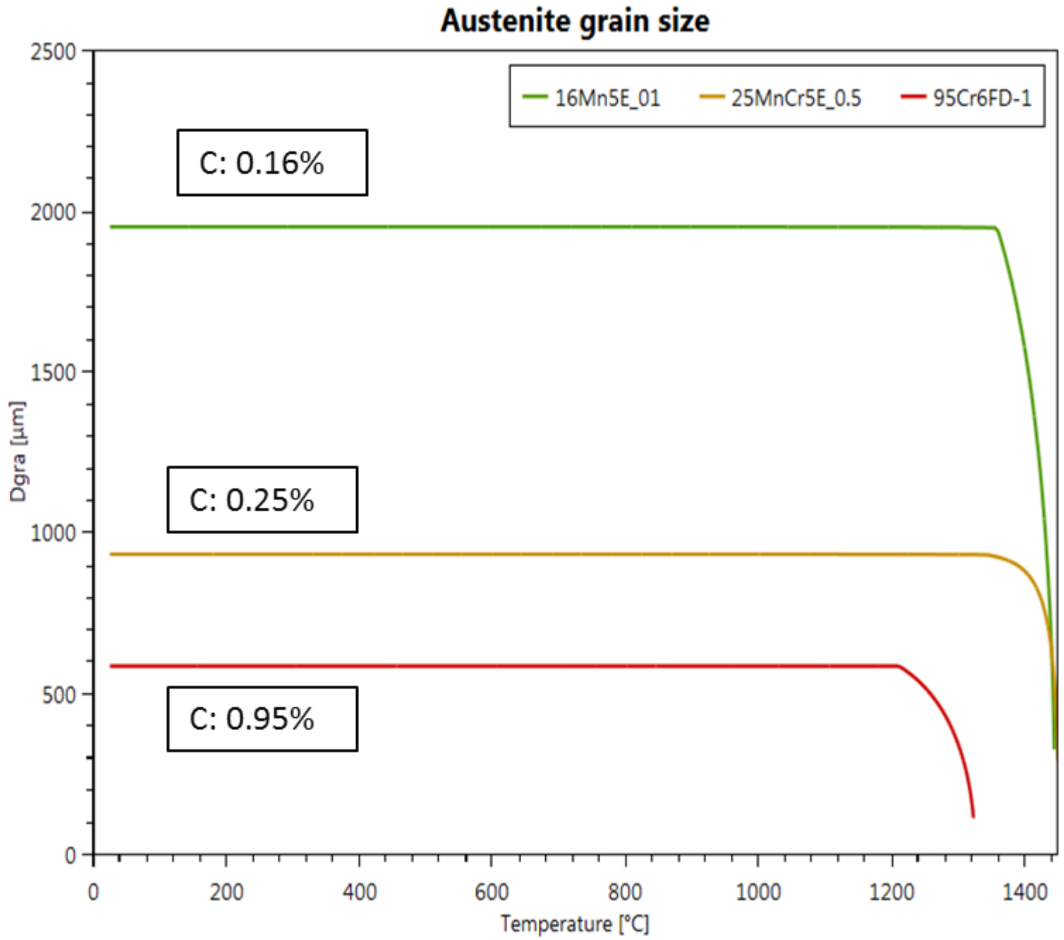
Carbon equivalent for peritectic reaction

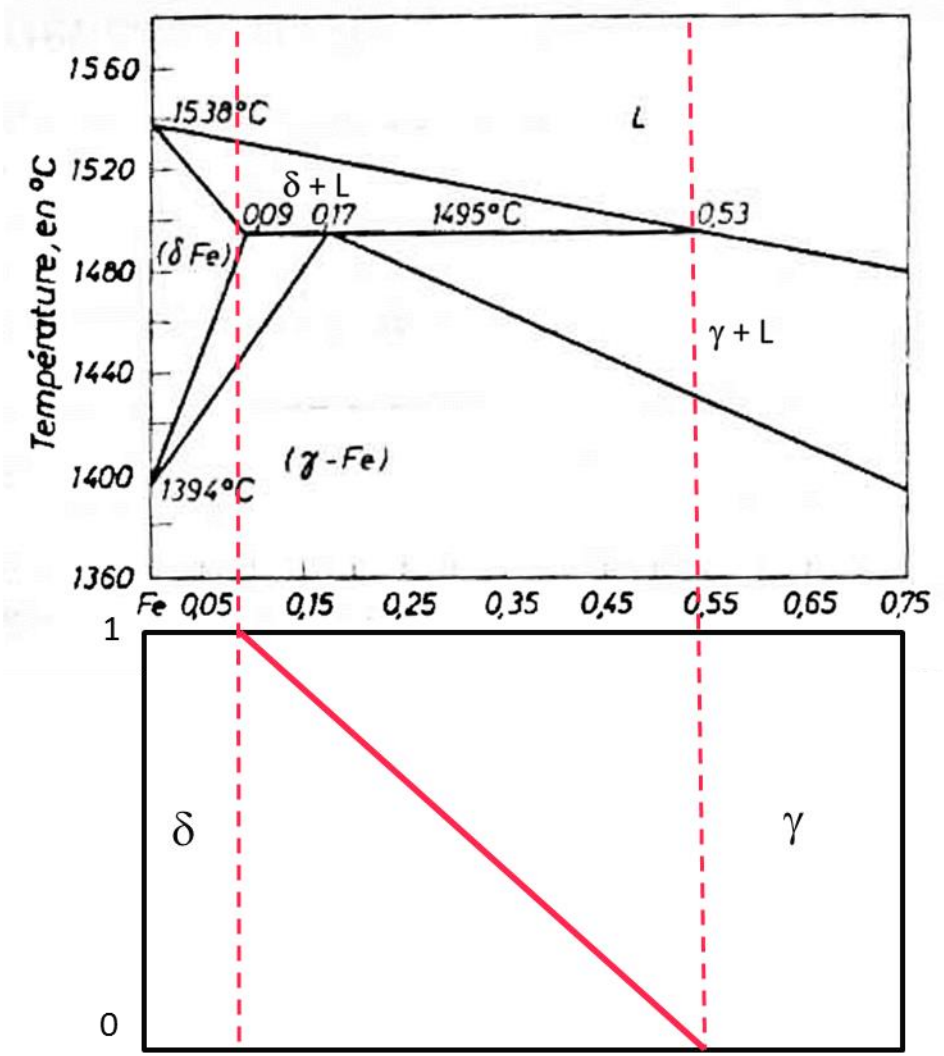
Cp = C +0,02*Mn+0,04*Ni-0,1*Si-0,04*Cr-0,1*Mo-0,7*S

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

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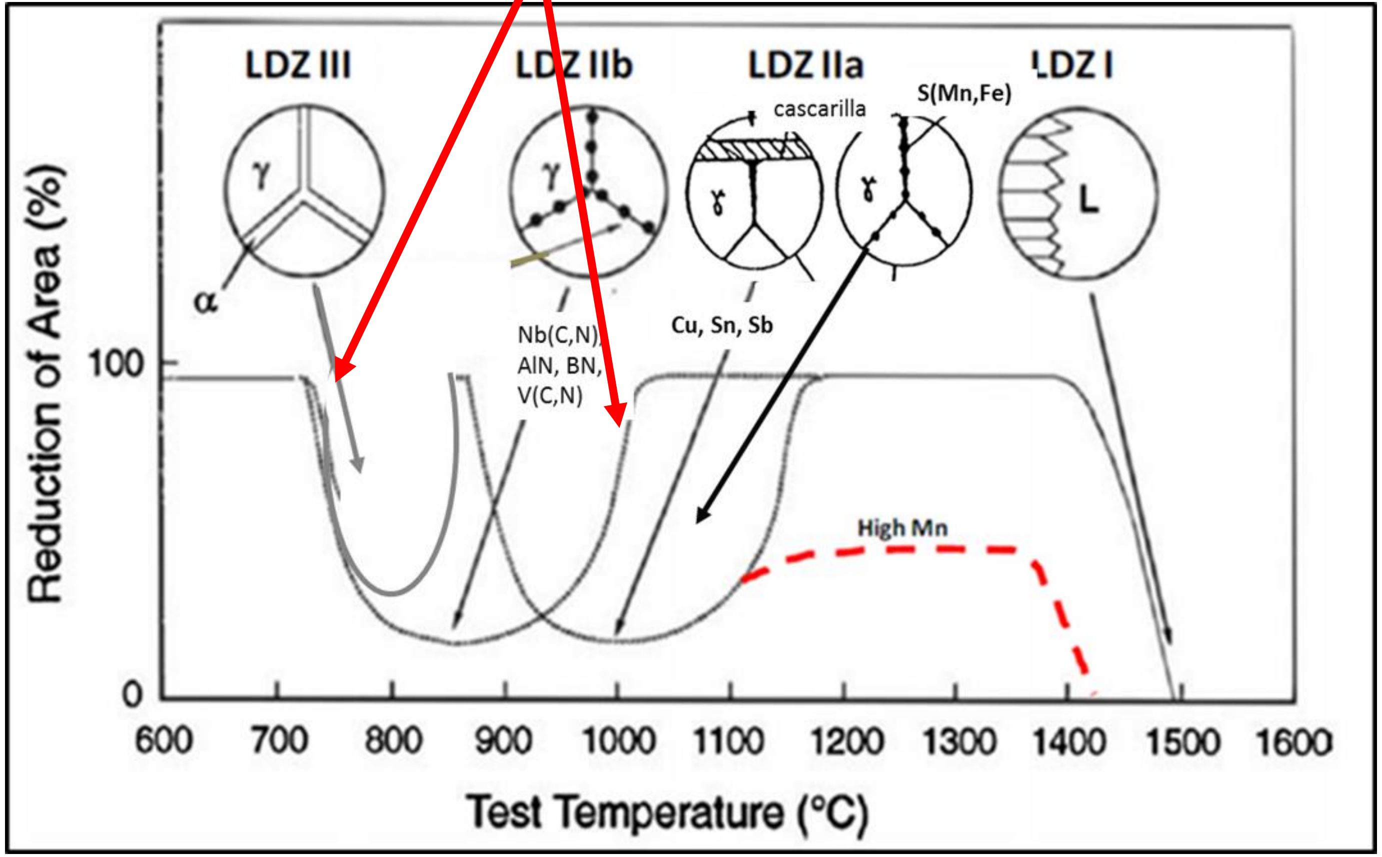
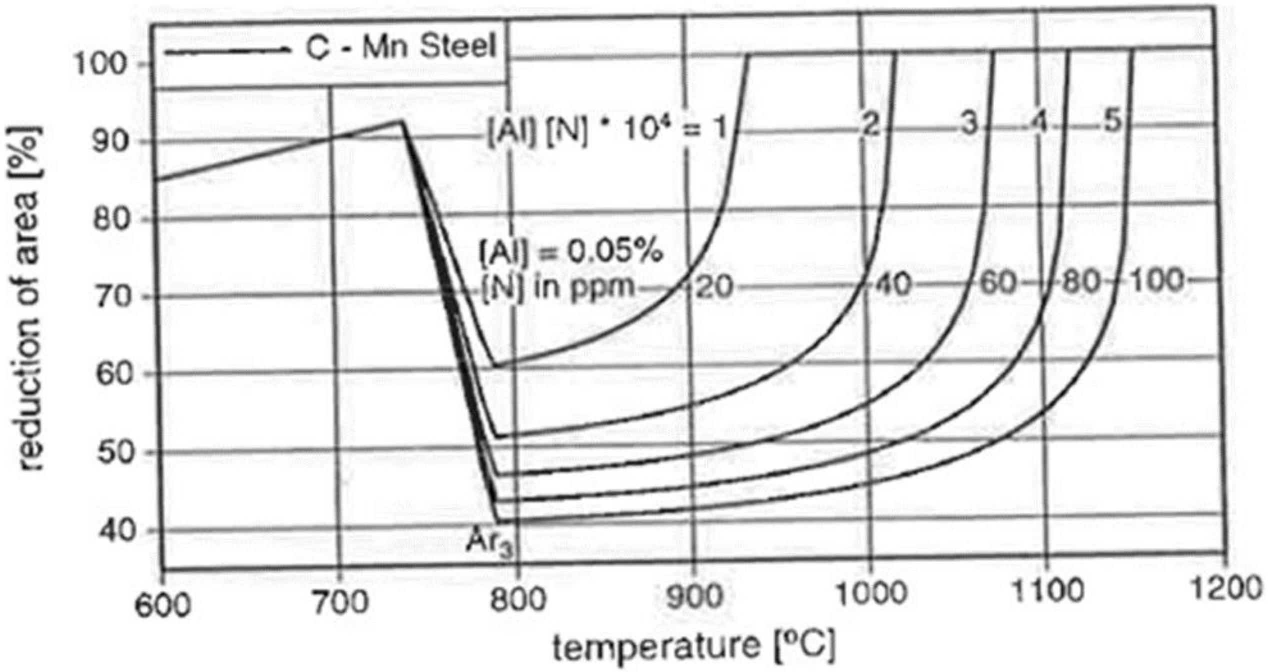
Low ductility troughs during solidification and cooling. Those ductility troughs influence the continuous casting semis quality.

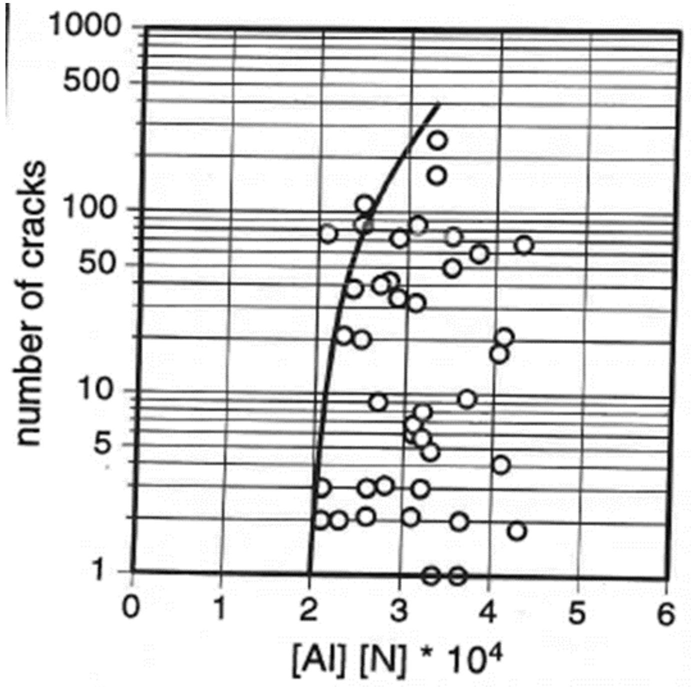
Current presentation
Surface cracks analysed



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

3. Influence of the microalloying elements on hot ductility

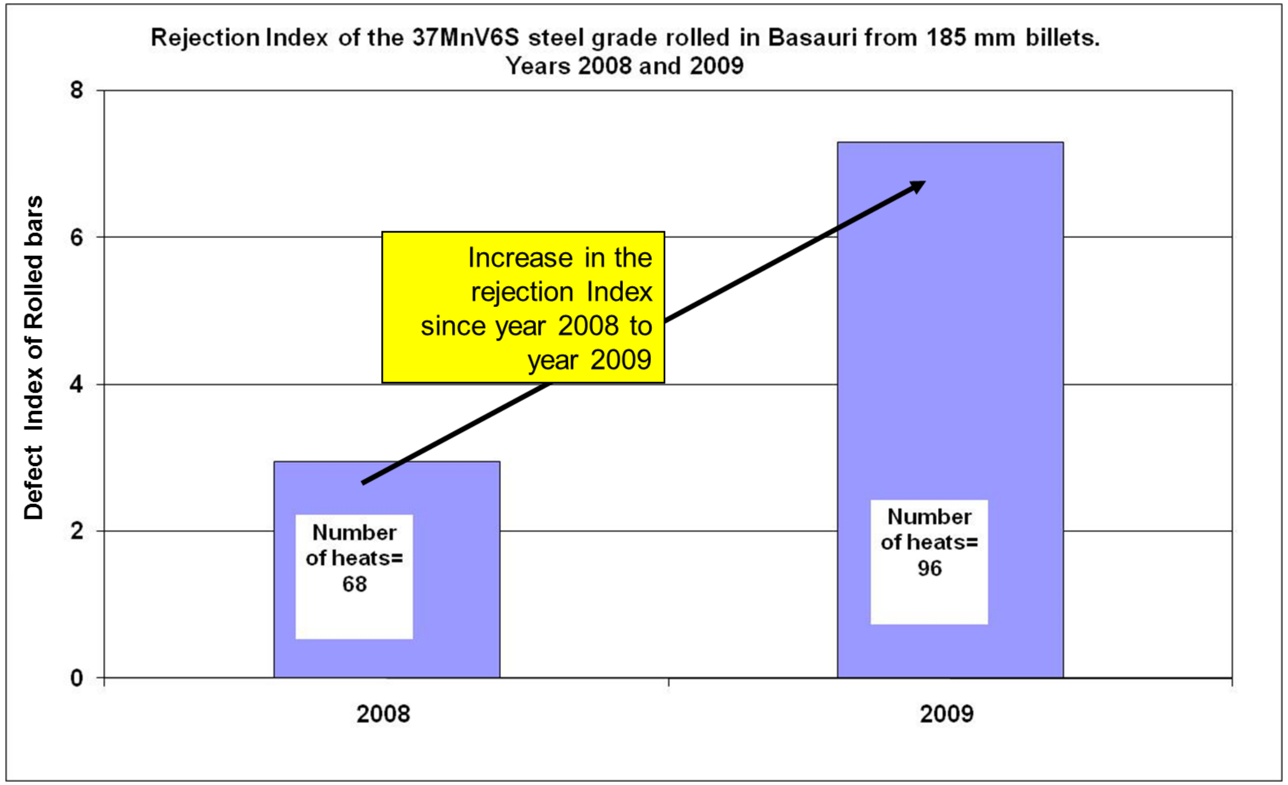
Influence of the AlN

37MnV6S

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

37MnV6E

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



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

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Influence of the AlN

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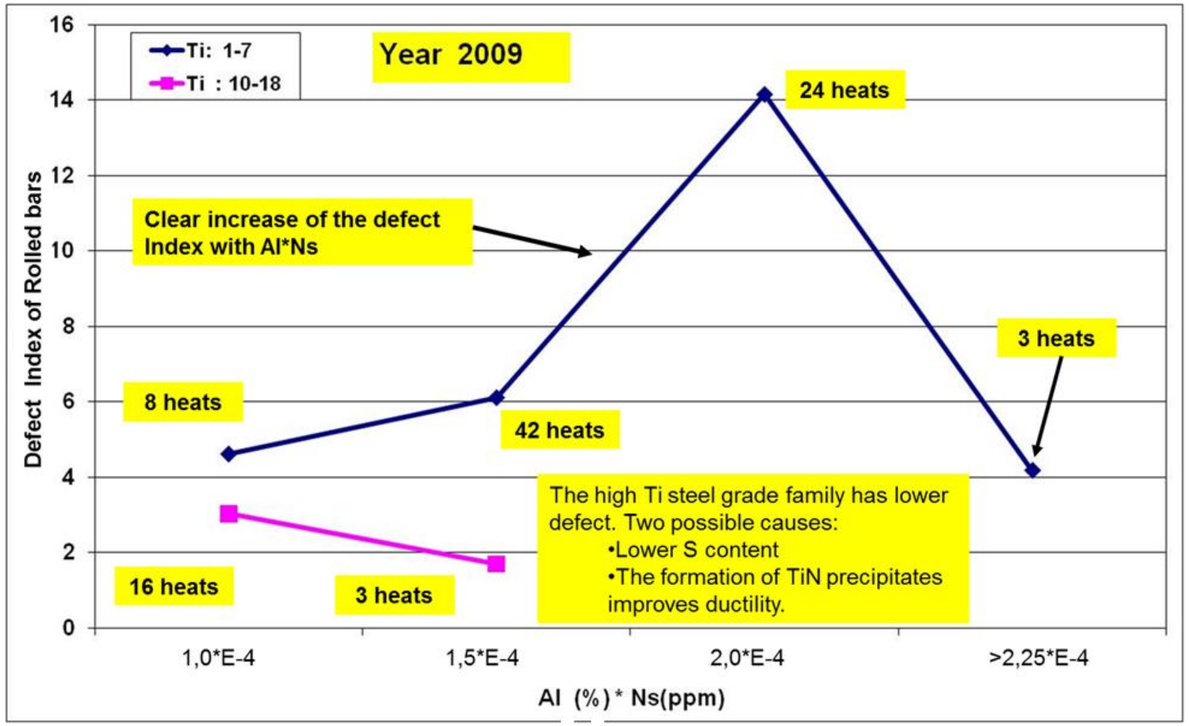
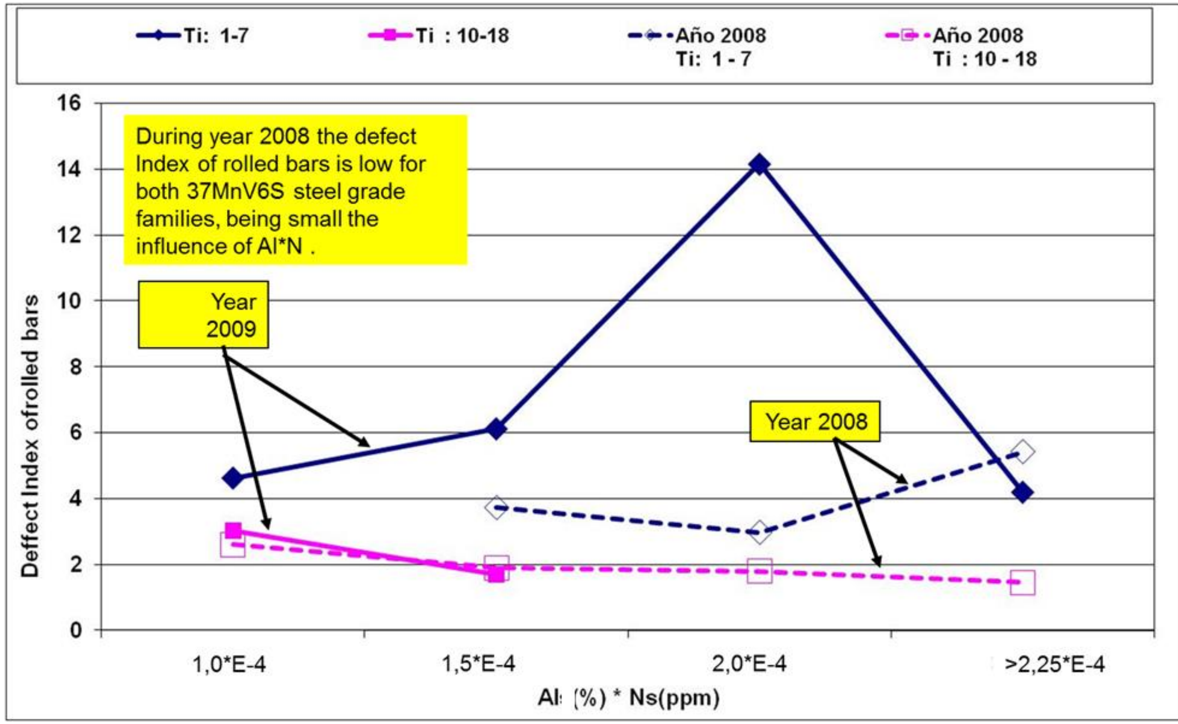
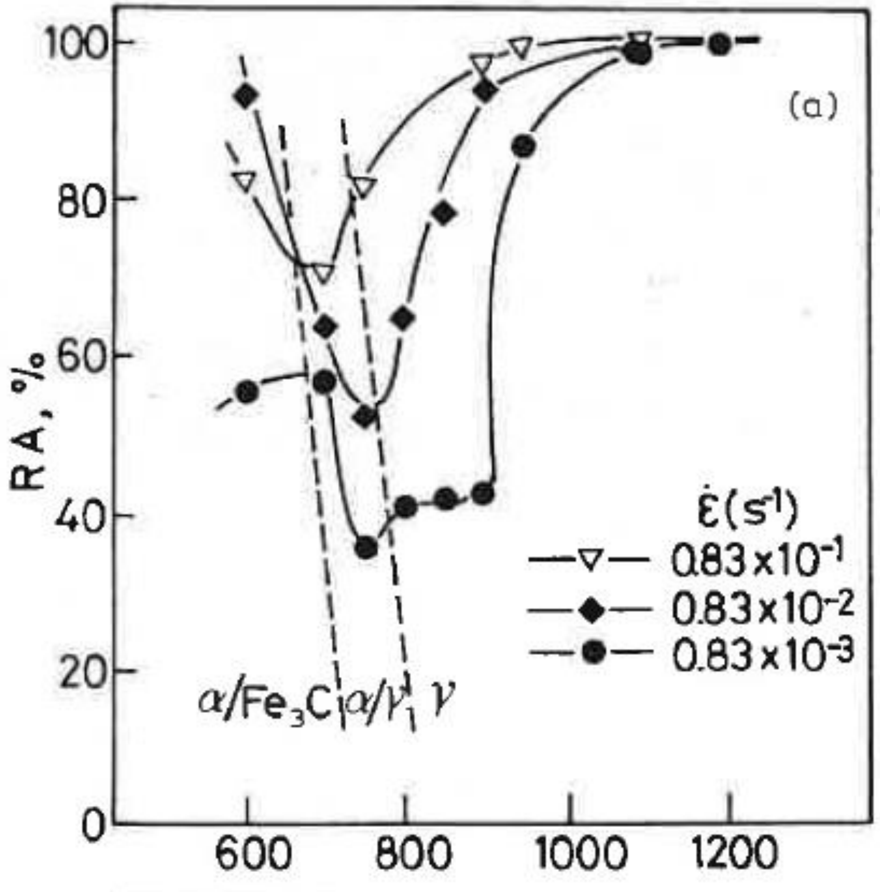




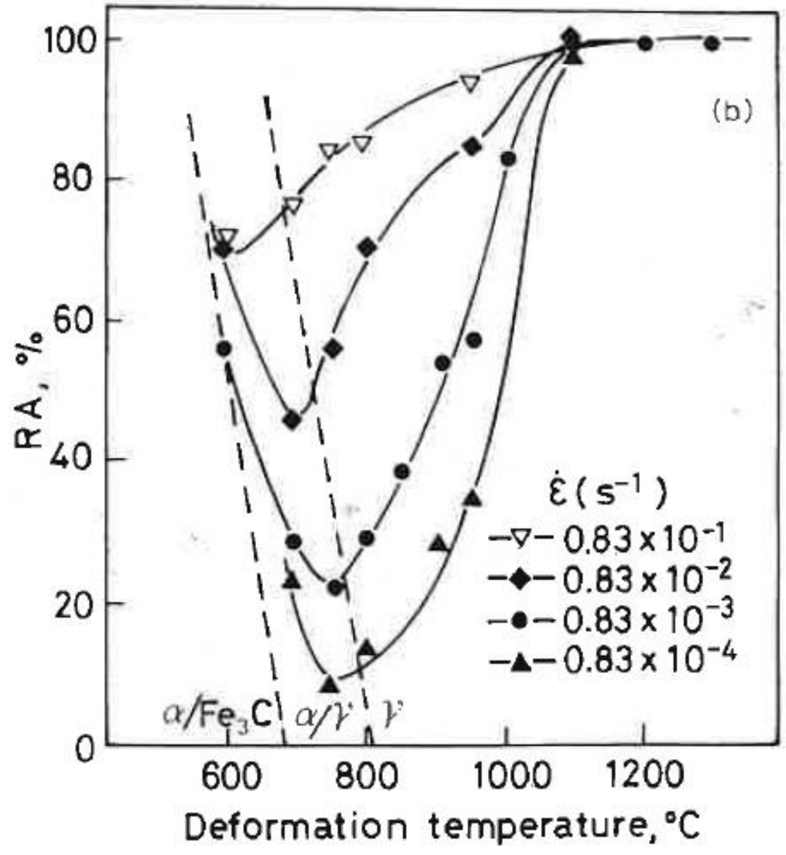
In order to decrease the steel tendency to cracking, the Ti content should be as high as possible in the range of the steel grade specification.

3. Influence of the microalloying elements on hot ductility

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

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

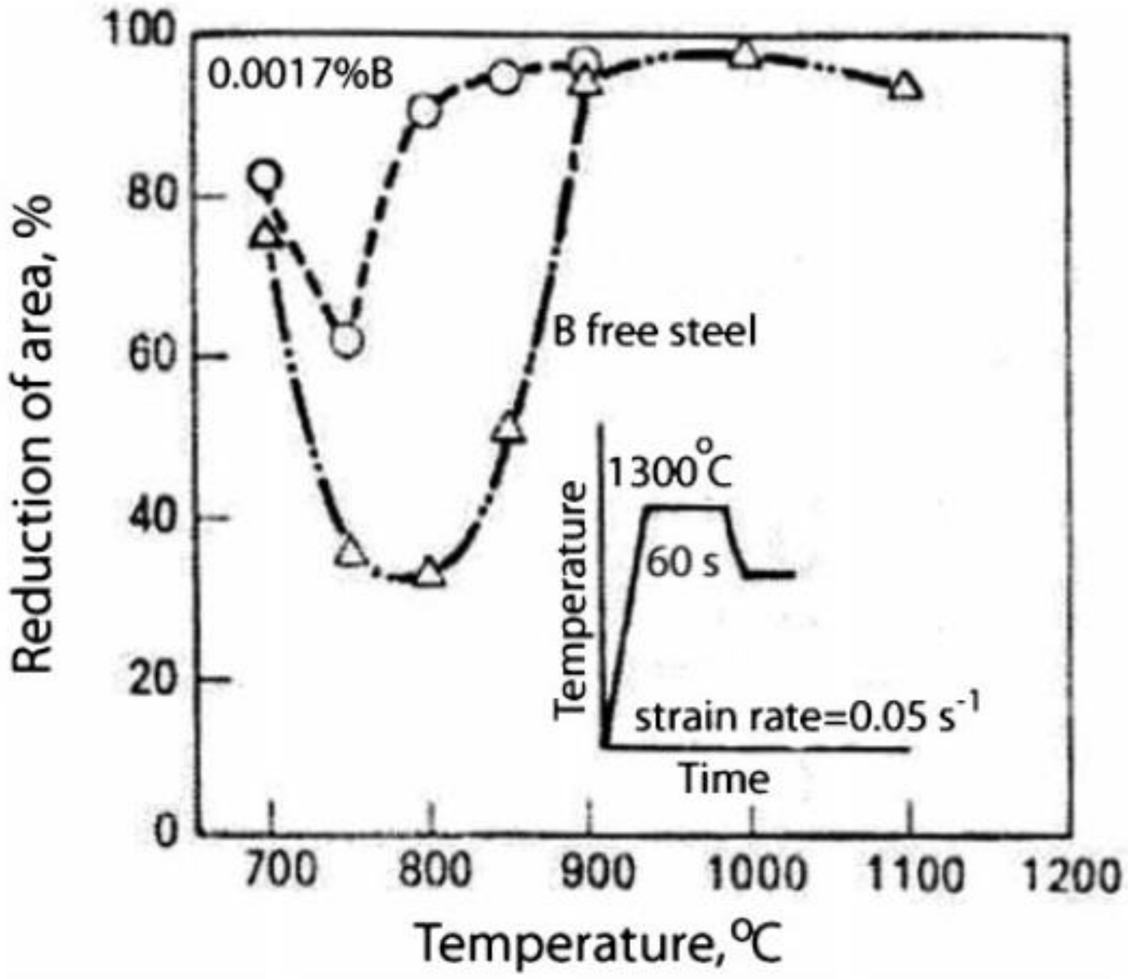
Y. Mahera et al. Mat Sci. and Tech. 1990, V.6, 793-806

3. Influence of the microalloying elements on hot ductility

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.

4. A Methods to avoid intergranular cracking: Strand temperature cycling

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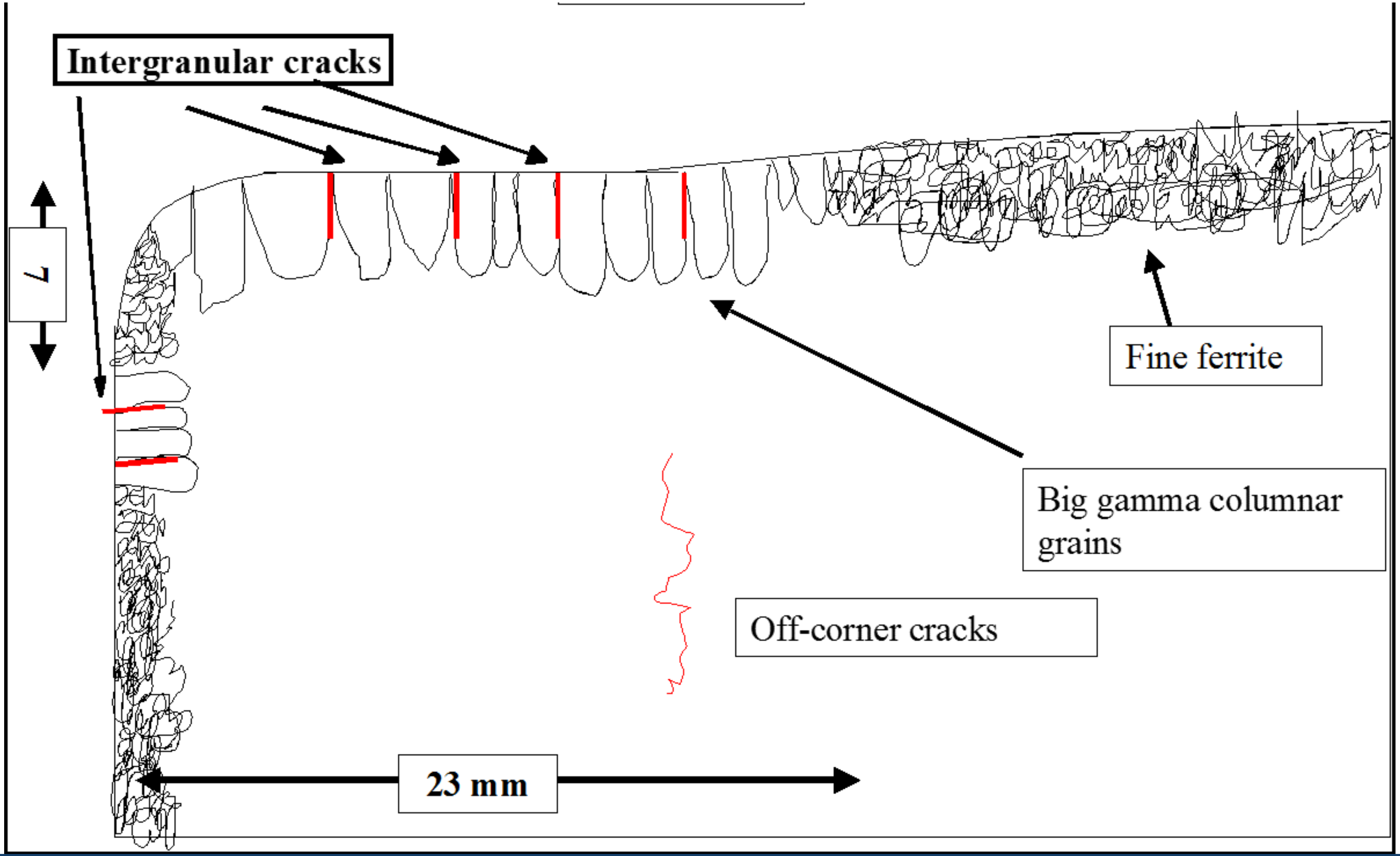
Intergranular cracks :19MnNbV5C steel. Billet as cast microstructure



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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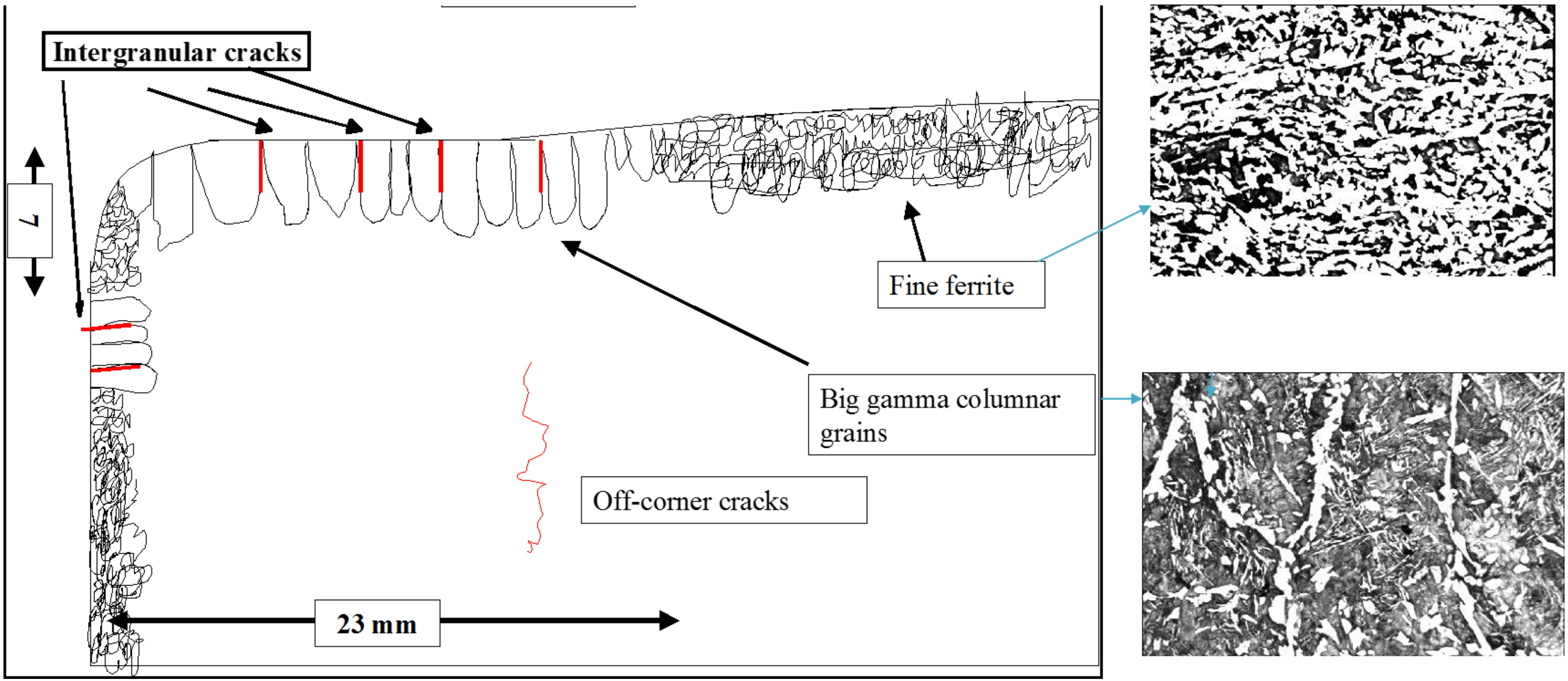

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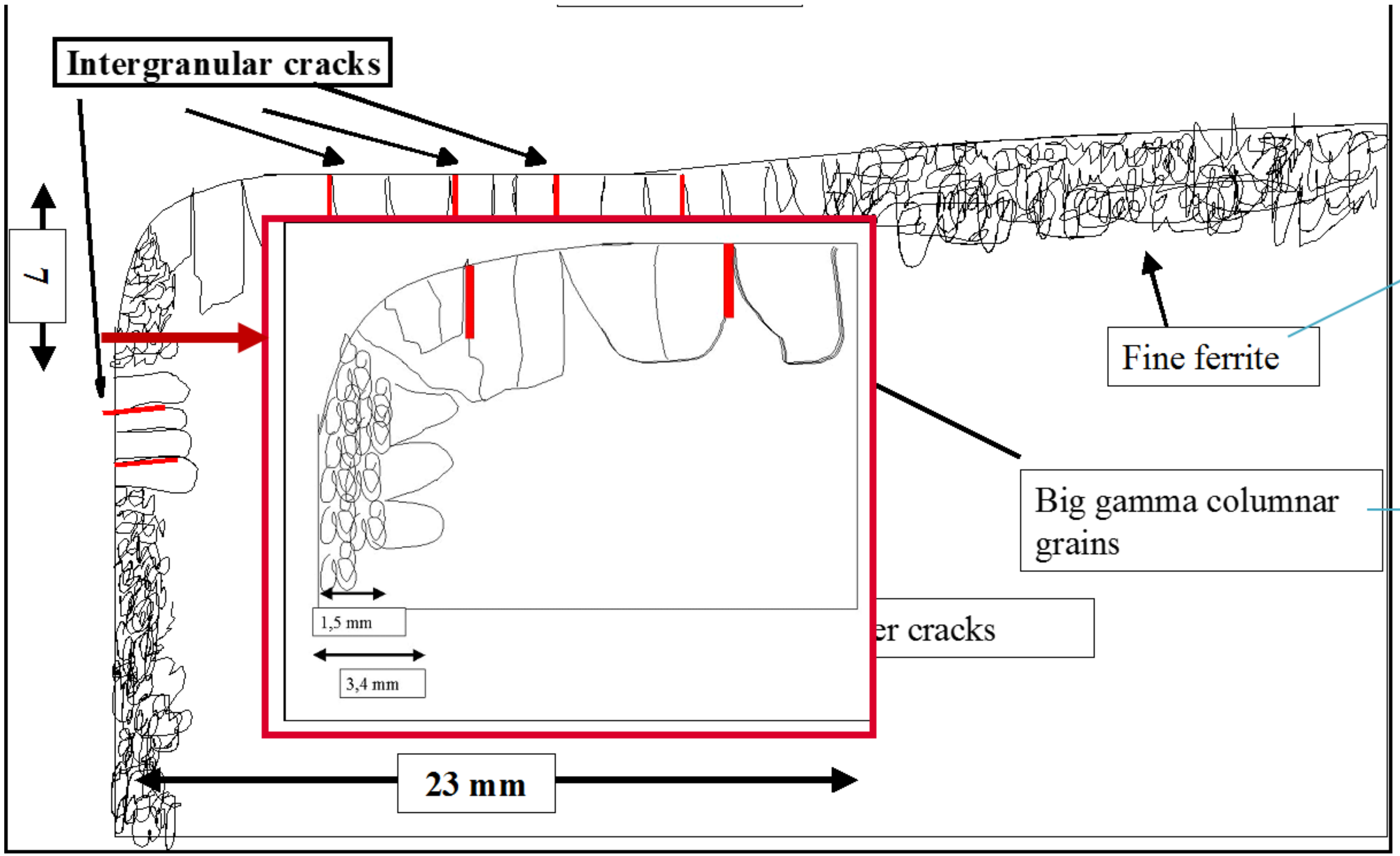
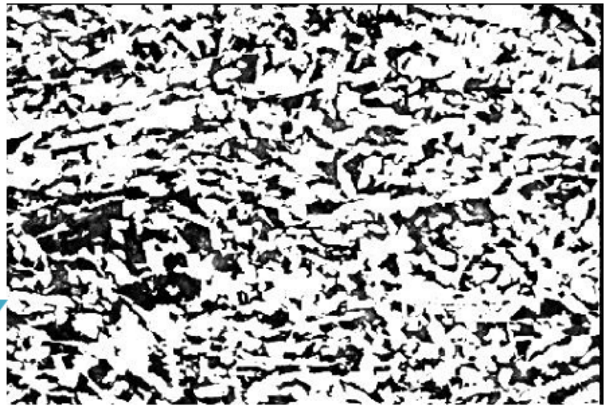
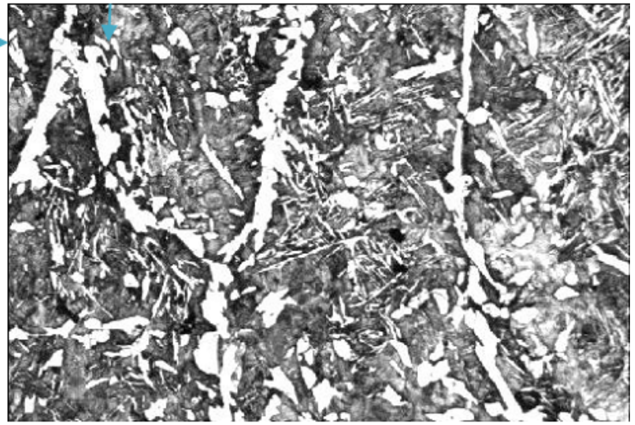
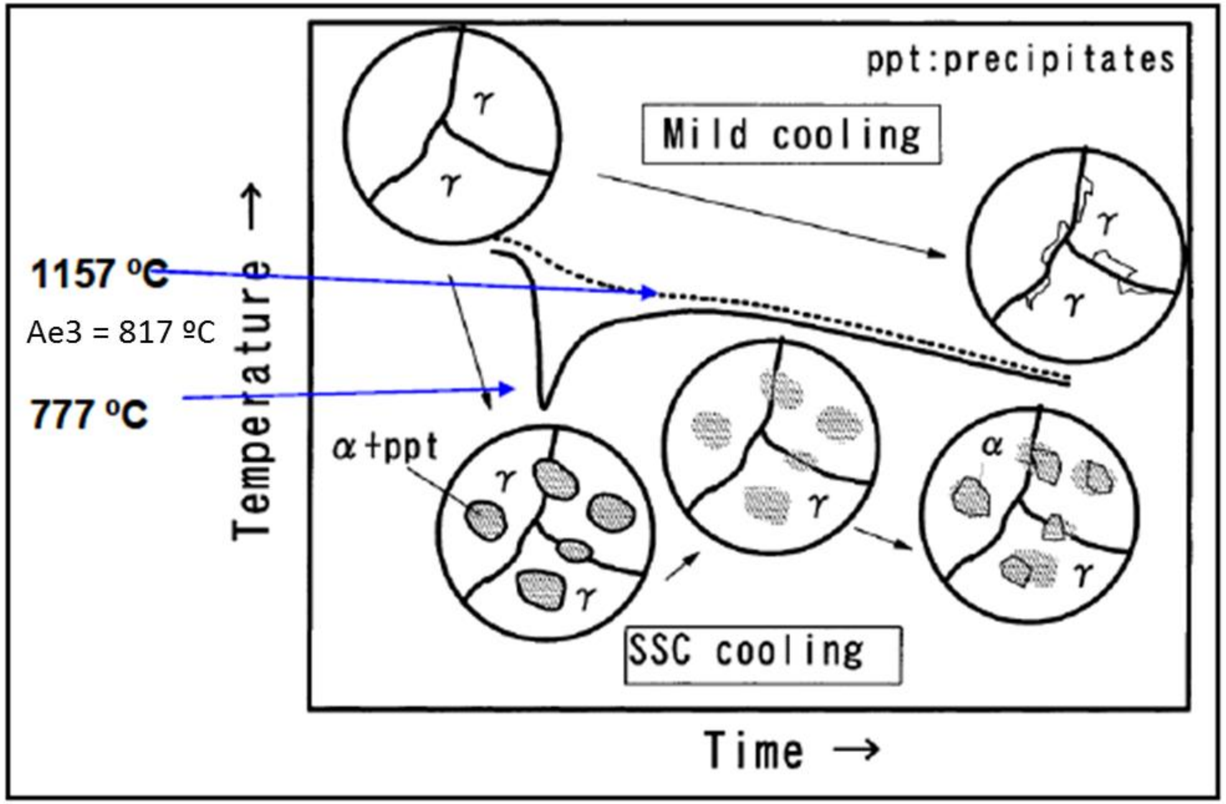


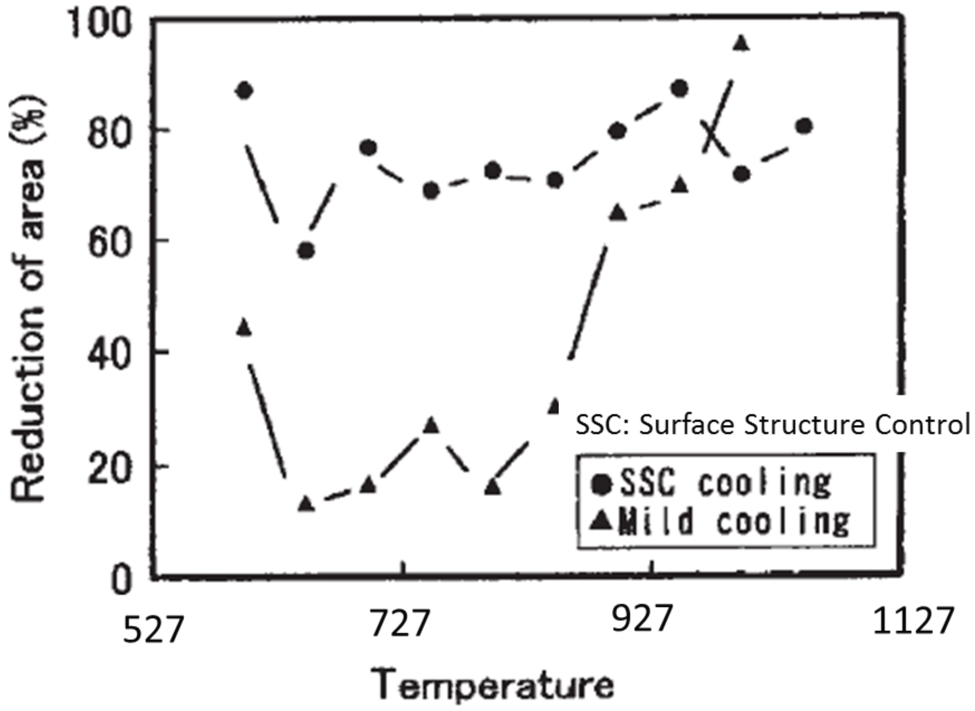




4. A Methods to avoid intergranular cracking: Strand temperature cycling

SSC: Surface Structure Control





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.

4. A Methods to avoid intergranular cracking: Strand temperature cycling

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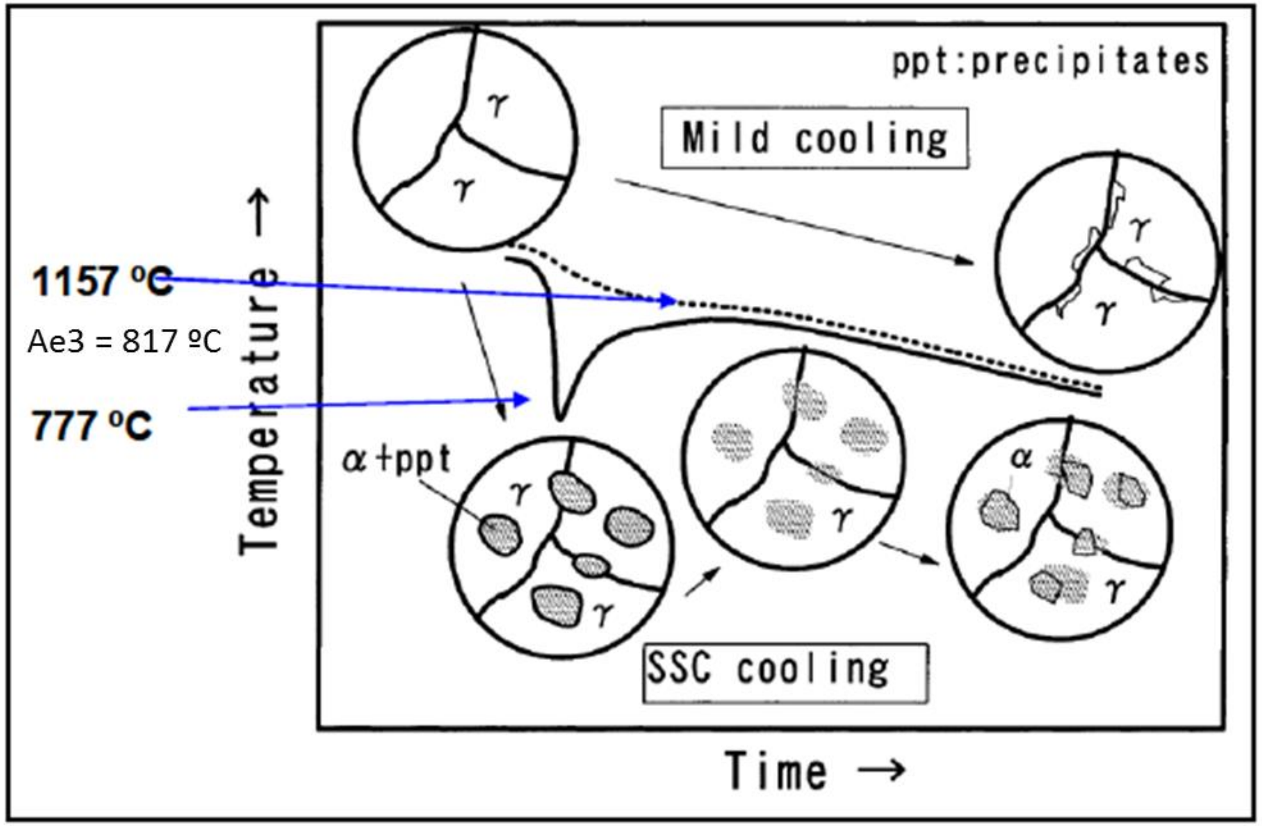

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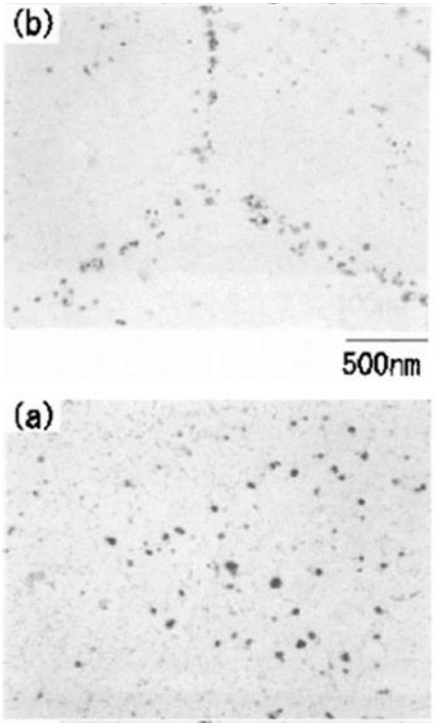
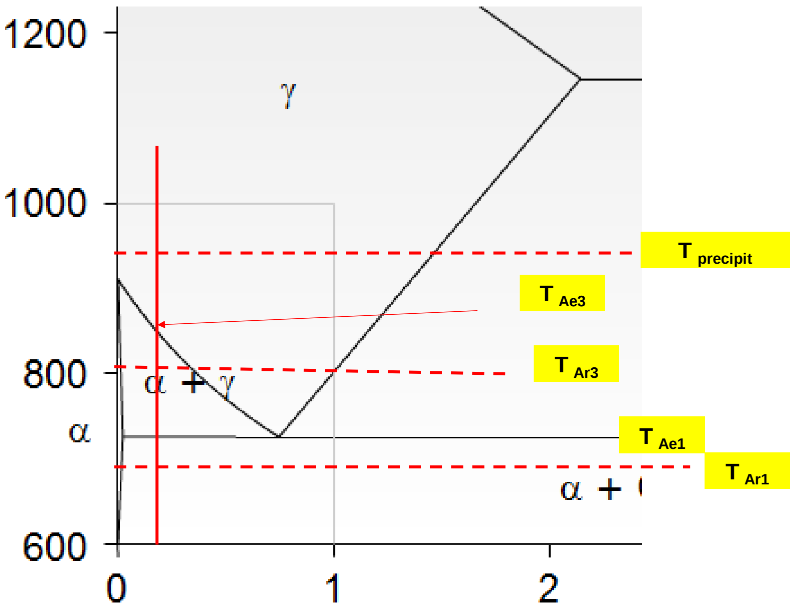


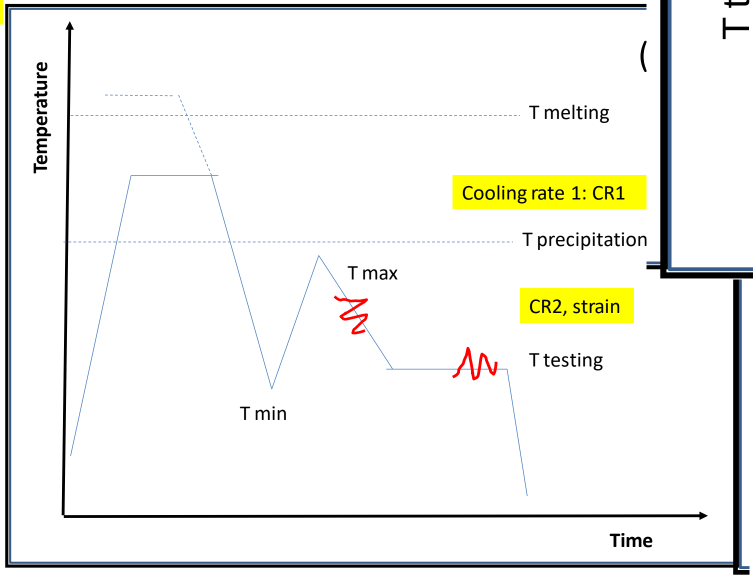
Differences on the precipitates distribution after:

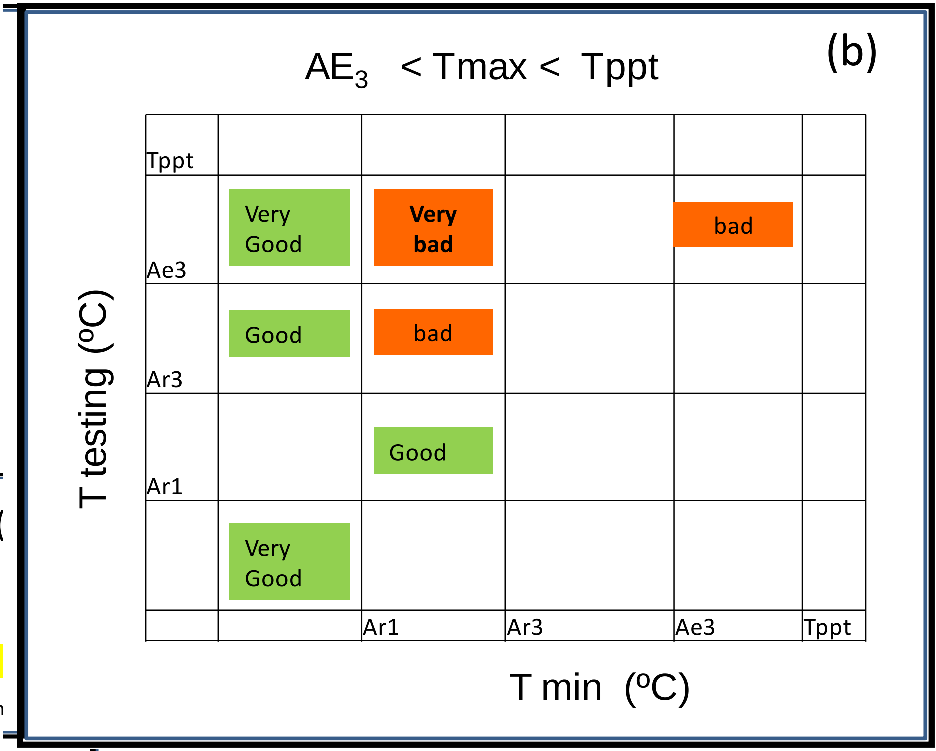
a) SSC cooling, homogenous precipitation
b) Mild cooling: precipitation at the austenitic grain boundaries

4. A Methods to avoid intergranular cracking: Strand temperature cycling

SSC: Surface Structure Control



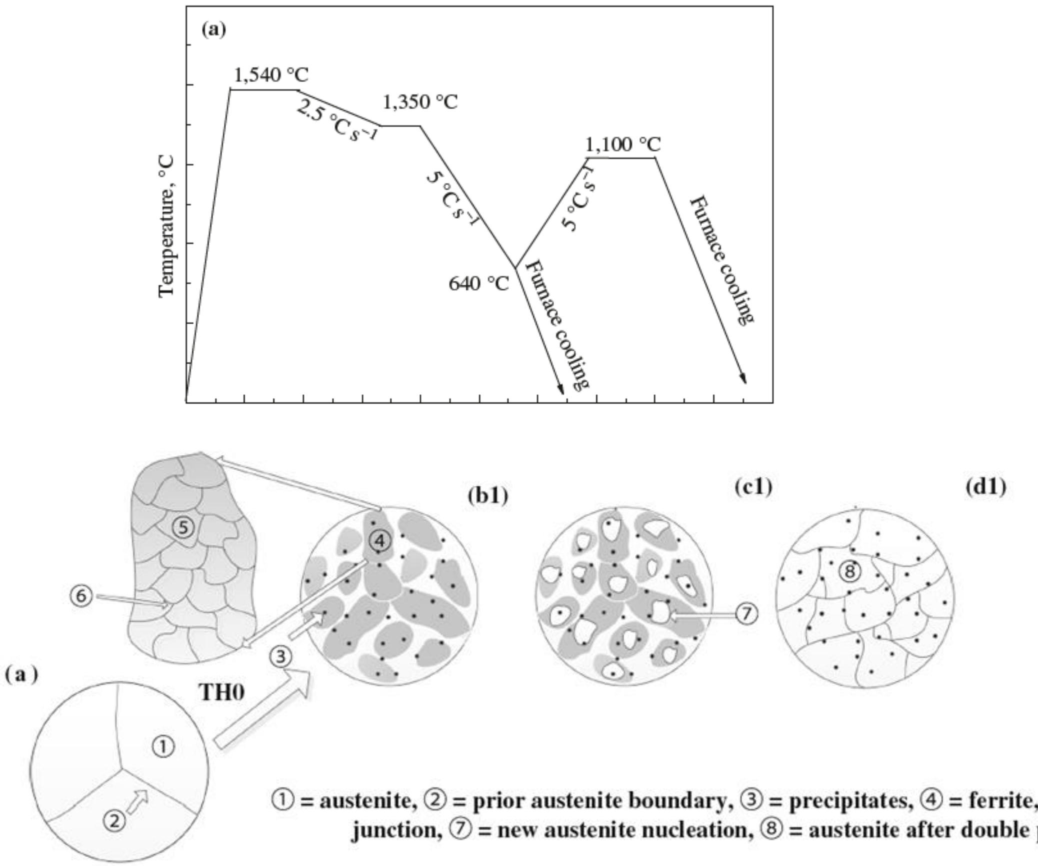




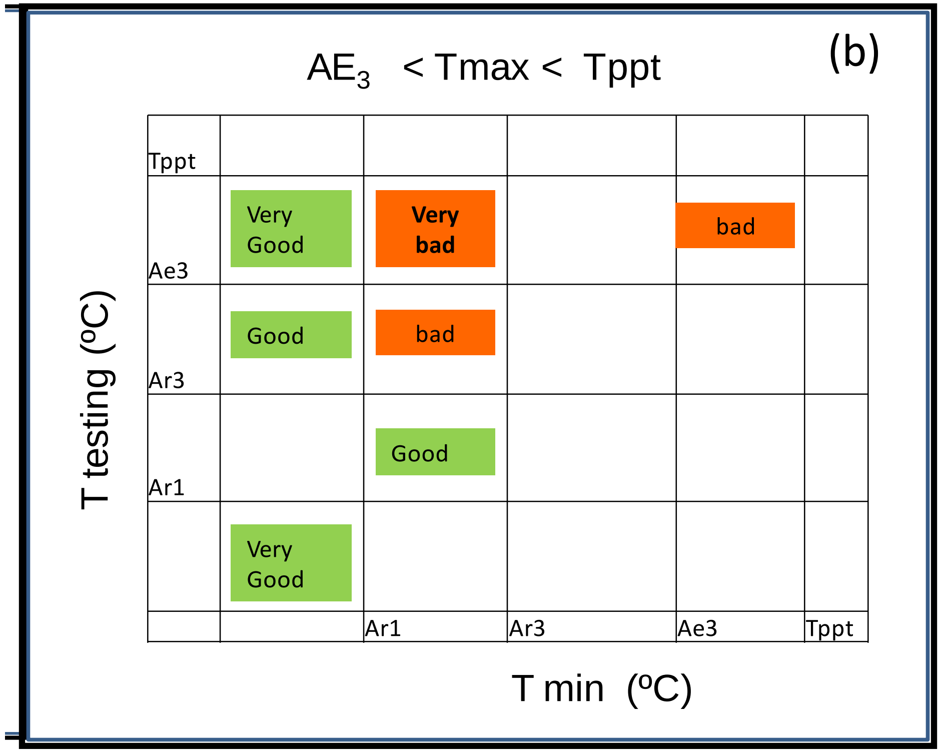
RFCS PMAP project

4. A Methods to avoid intergranular cracking: Strand temperature cycling

SSC: Surface Structure Control



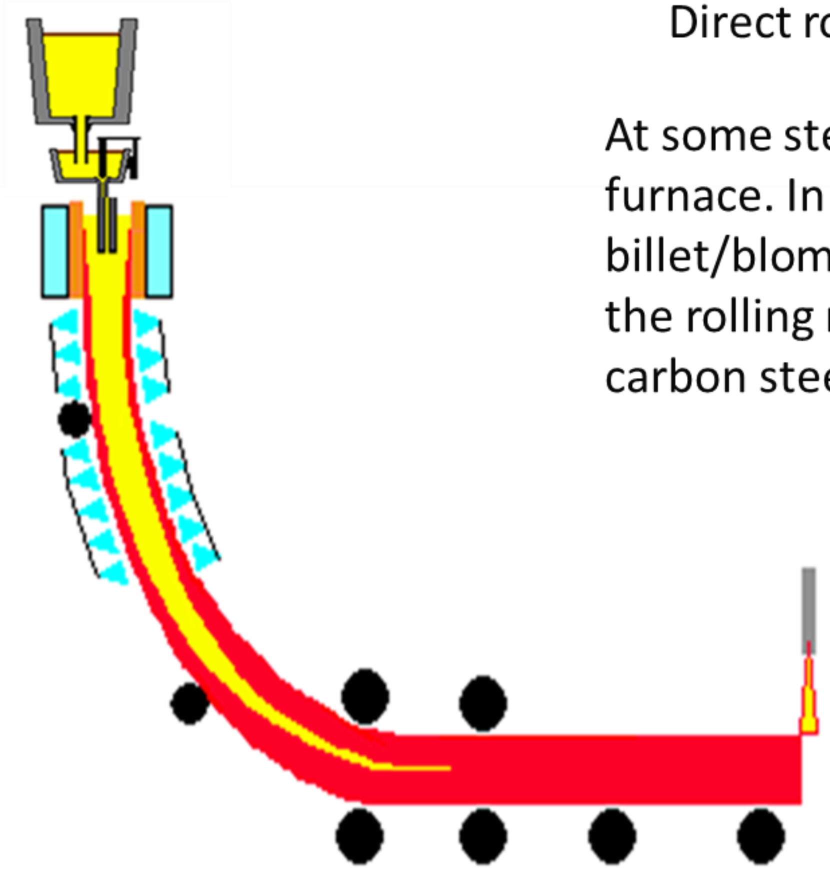
① = austenite, ② = prior austenite boundary, ③ = precipitates, ④ = ferrite, ⑤ = ferrite grain, ⑥ = triple junction, ⑦ = new austenite nucleation, ⑧ = austenite after double phase transformation



Jiang Liu, Guanghua Wen*, Yunfeng Li, Ping Tang and Linqing Luo
High Temp. Mater. Proc. 2016; 35(7): 653–659

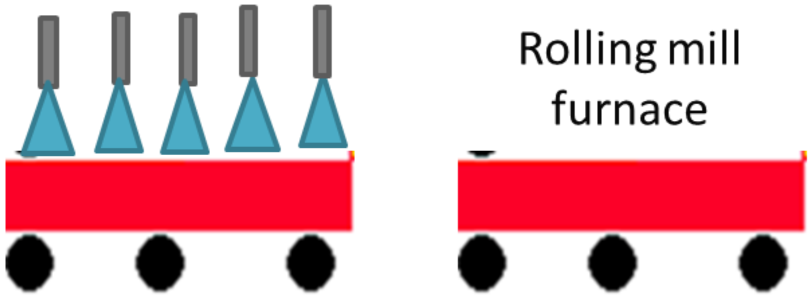
4. A Methods to avoid intergranular cracking: Strand temperature cycling

Industrial aplications



Direct rolling casting

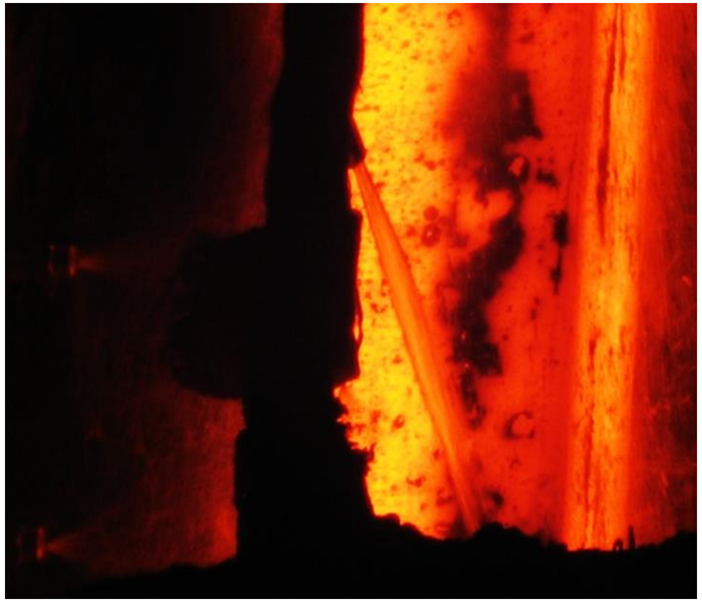
At some steel mills the billets/blooms are hot charged on the rolling furnace. In order to avoid rolling the semis with the as-cast structure a billet/blom surface temperature cycling is carried out before hot charging in the rolling mill furnace . This technique is an advantage when rolling low carbon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



4. A Methods to avoid intergranular cracking: Strand temperature cycling

Example of a hard temperature cycling

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.

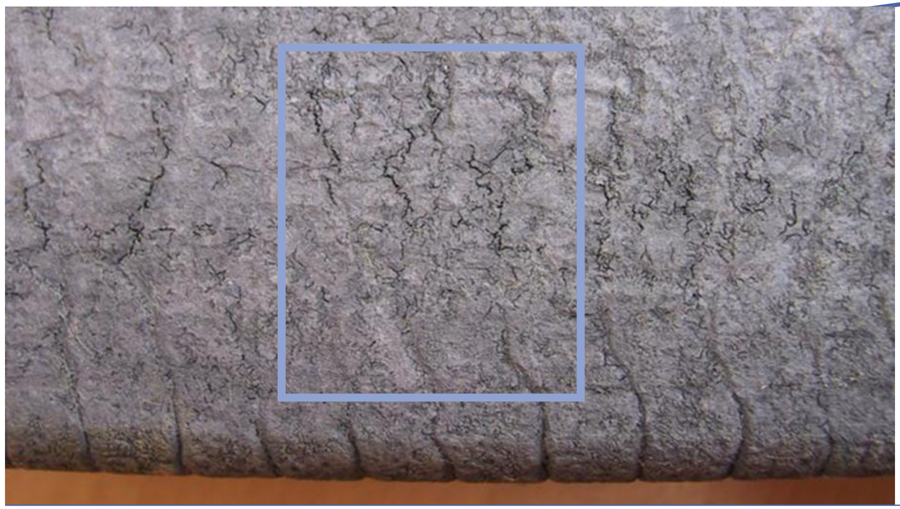


4. A Methods to avoid intergranular cracking: Strand temperature cycling

Example of a hard temperature cycling

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

Transversal cracks on OSM

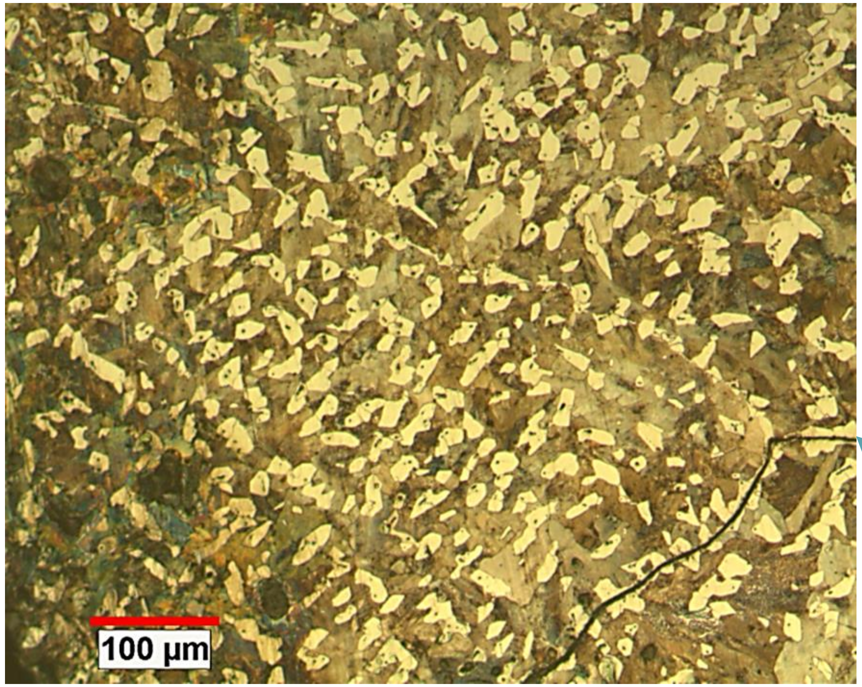


The area where the jet impacted present intergranular and transversal cracks.
The other corners don´t present these defects.

4. A Methods to avoid intergranular cracking: Strand temperature cycling

Example of a hard temperature cycling

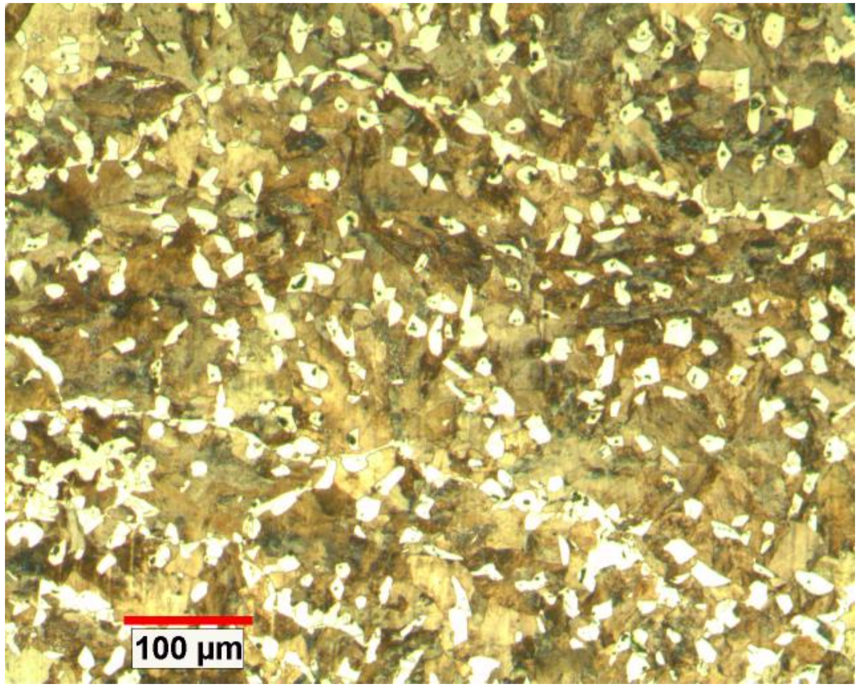
Cracked corner



Intergra-nular Crack at OSM

- Ferrite content: 16,1%,
- Ferrite average size: 135.6 μm^2
- Surface distance 1 mm.
- The ferrite nucleated on prior precipitated particles, mainly MnS, which were favored by the cooling of the jet impact.

Non-Cracked corner



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

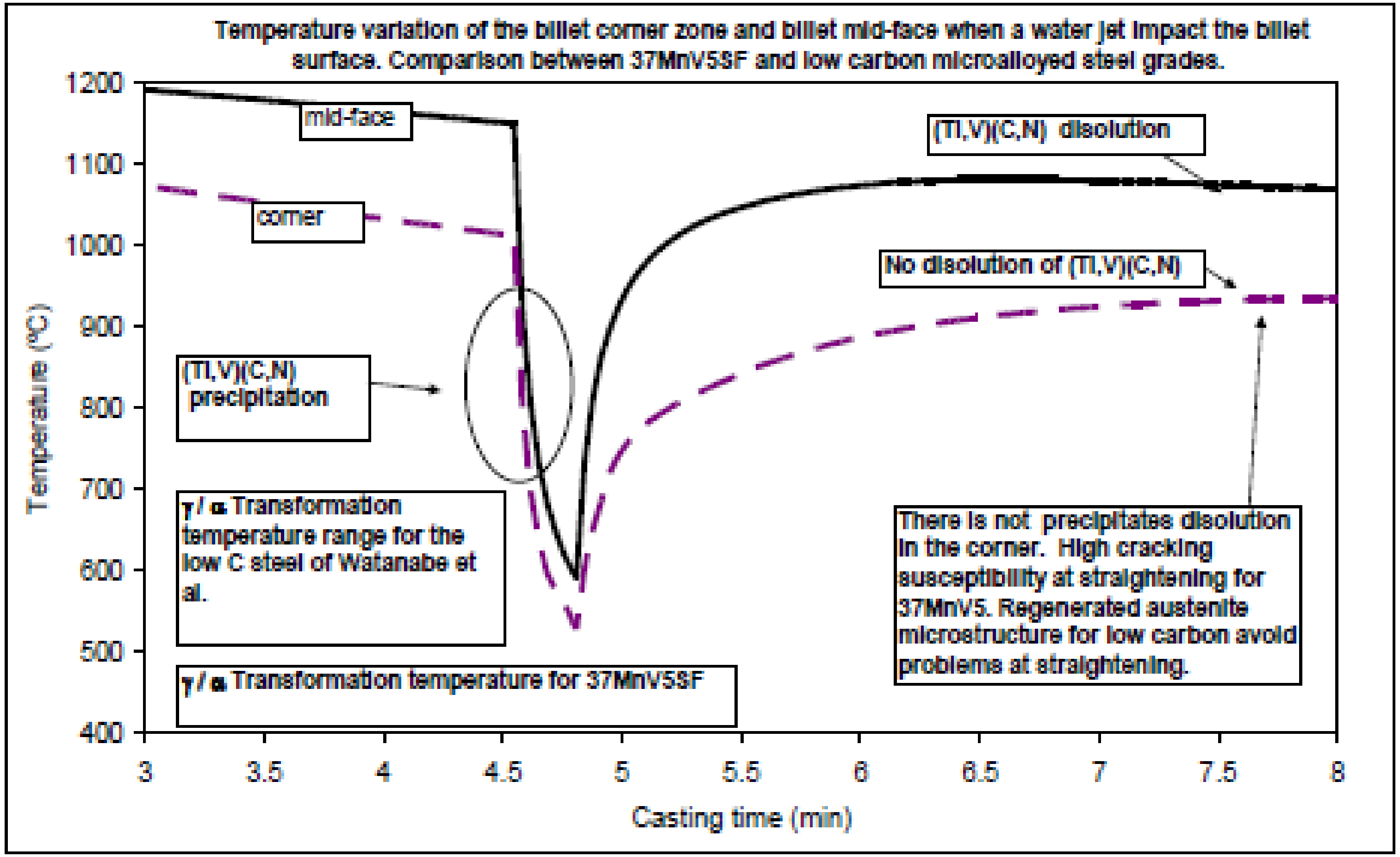
4. A Methods to avoid intergranular cracking: Strand temperature cycling

Example of a hard temperature cycling

- Due to the high cooling rate, the g/a transformation start temperature lowers to around 490 ºC

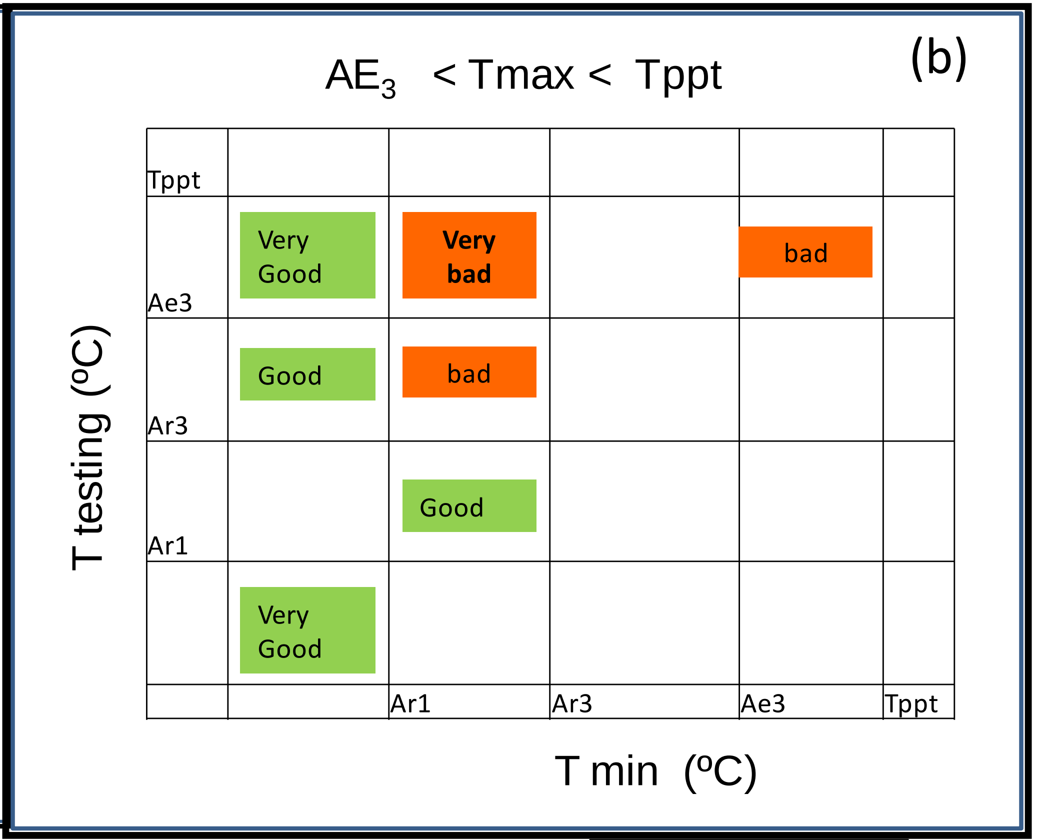
- No γ/α transformation takes place during the jet impact at the area near the corners of the billet.

- During the heat recovery, (Ti,V)(C,N) precipitates are dissolved in the mid face but not in the billet corner.

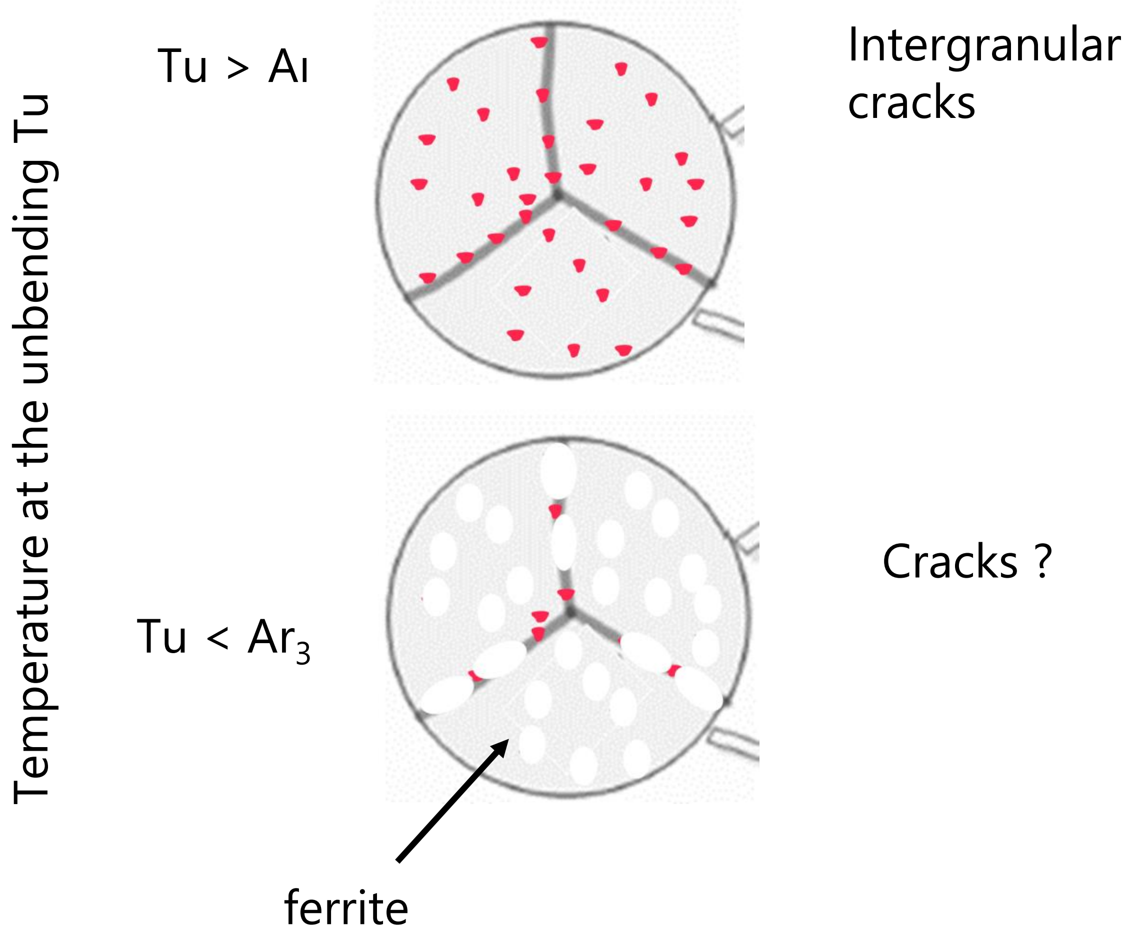


4. A Methods to avoid intergranular cracking: Strand temperature cycling

Example of a hard temperature cycling



$T_{min} > T_{Ar1}$

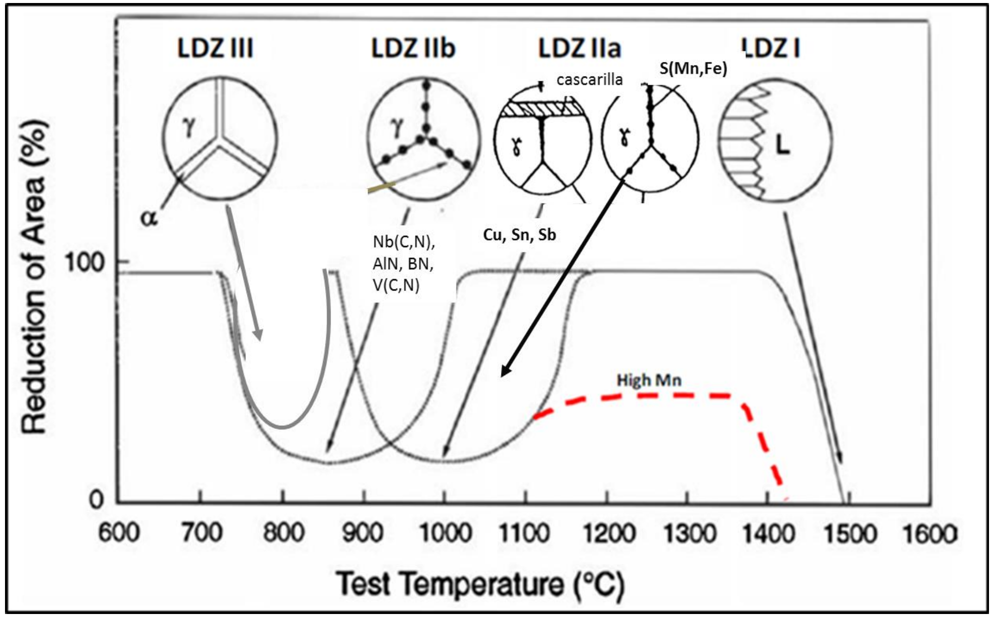


5. conclusions

5. CONCLUSIONS

The best tips to avoid intergranular cracks are:

1. Avoid semis reheatings and stresses inside the mould.
2. Ensure a temperature along the strand until the un-bending higher than the precipitation temperature.
3. Reach the un-bending at a lower temperature than the γ / α transformation. “cold casting”
4. Optimize steel composition and microalloyed content.
5. Ensure a proper performance of the secondary cooling.
6. Perform a strand temperature cycling?



THANK YOU VERY MUCH FOR YOUR ATTENTION.

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