AVOIDING SURFACE CRACKS IN A LOW C, Al-Killed, Nb, V, N, 240mm SQUARE BLOOM CAST STEEL[1]

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SUMMARY

It is well known the high tendency for surface cracks of low C, Al-Killed, Nb, V, N steels in continuous cast products. In order to avoid this problem, an investigation of CC parameters using the physical thermo-mechanical simulator Gleeble 3500 was conducted in this work. Tests were designed and the results computed according to the 2^K factorial technique using a commercial statistical software, Minitab .

Soft cooling in the secondary cooling zone and higher casting speeds were found to be important factors directly related to surface cracks.

Key words: surface cracks, hot ductility, Gleeble.

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1. INTRODUCTION

The production of low carbon, Al-Killed steels, microalloyed with Nb, N and V can be troublesome as far as surface cracks are concerned during the steel casting when the continuous casting (CC) process parameters are not optimized.

In this paper is presented an optimization study on CC parameters for the production of a DIN20MnCrS5 Modified steel.

This steel is very sensitive to network as well as transverse cracks at the surface of the bloom. The network cracks are mainly located near the bloom corners in the inner radius. On the other hand, the transverse cracks occur mainly at the inner radius corners, at the bottom of the oscillations marks.

The depth of the network cracks ranges from 0,3mm up to 3,0mm and the transverse cracks, in the most severe cases, can go as far as 50mm deep.

During visual inspection it is not possible to detect any crack, except the most severe cases. This is due to the hiding effect of the scale at bloom surface.

Fig.1 illustrates typical network cracks at the bloom surface after acid pickling, observed by a stereoscopic magnifying glass.

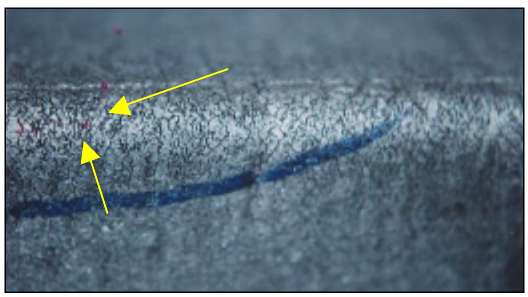

Fig.1. – Network cracks, indicated by arrows, presented at bloom surface after acid pickling

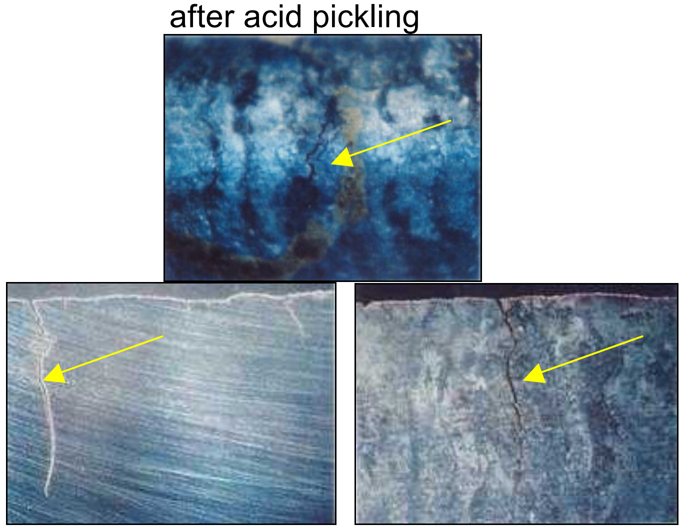

Fig. 2. Transverse Cracks at the bottom of oscillation marks, indicated by arrows, after acid pickling:

- top: surface corner
- bottom left: same crack after cutting the bloom
- bottom right: same crack after cutting the bloom and acid etching

According to the literature (6), surface cracks can be initiated inside the mould during the early stages of solidification. They can grow during the descending journey of the bloom through the continuous casting machine (CCM).

Two zones are of special attention below the mould.

The first zone is the **secondary cooling zone**. If there is not a uniform temperature evolution at the bloom surface, tensile strength and fragile precipitates can be generated and so some crack initiation will take place.

The second zone is the **unbending zone**, where the bloom is submitted to a strong tensile strength in the inner radius. Even if there is neither a crack initiation inside the mould nor in the secondary cooling zone, it can occur at the bloom surface if the hot ductility limit is reached.

The present work will not analyze the crack initiation phenomenon inside the mould but only the dependence of hot ductility on some CC process parameters below the mould.

Fig. 3 shows a schematic of Gerdau Aços Finos Piratini's machine.

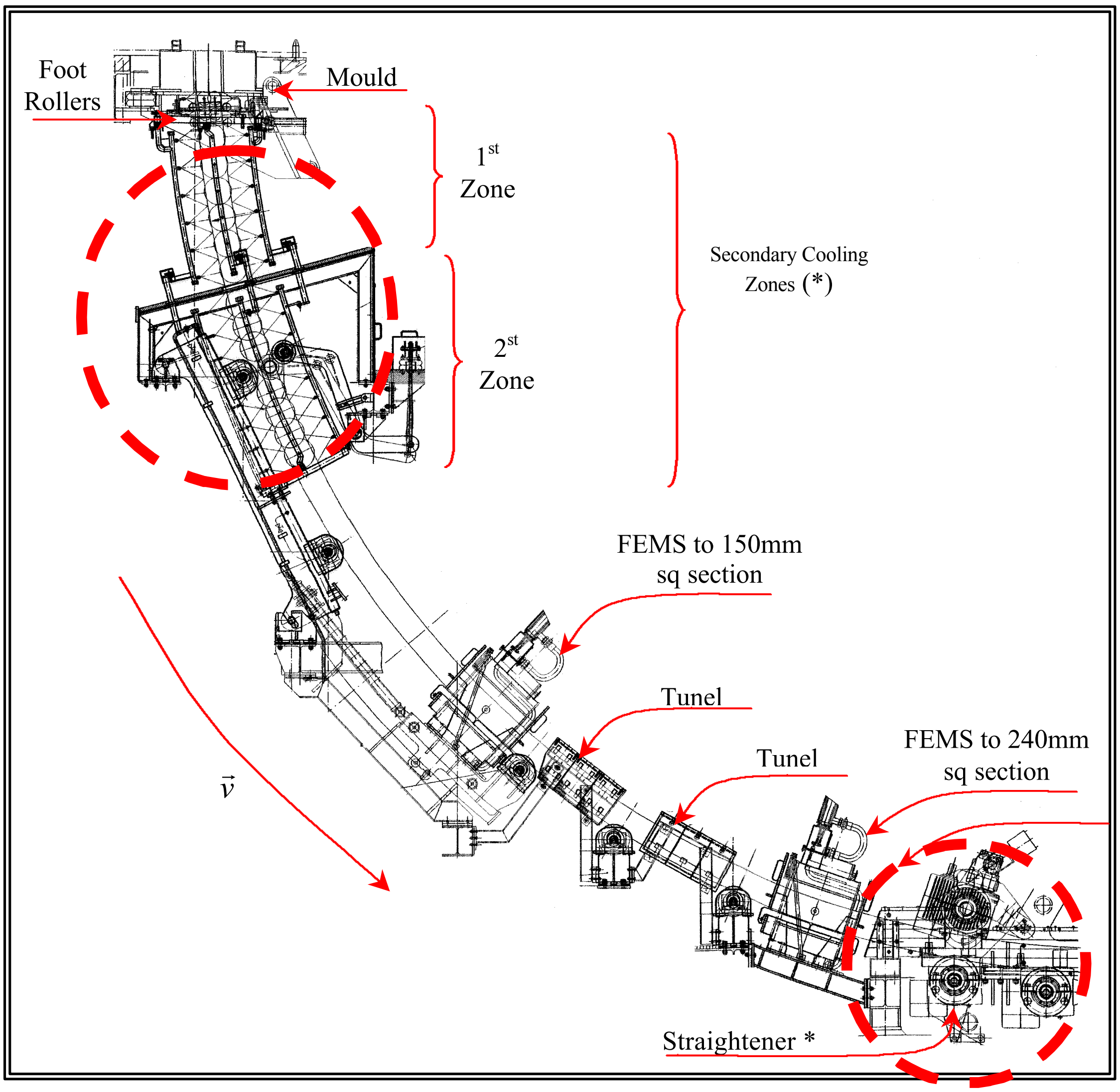

Fig. 3. Gerdau Aços Finos Piratini – CCM – Critical zones for surface cracks initiation/growth

It is well know (1...6) that the hot ductility is very dependent on:

- the *brittle temperature range*,
- the *strain rate* applied and
- *thermal history* of the bloom.

Fig.4 shows a typical *brittle temperature range curve*, were there are some troughs in hot ductility according to the temperature level. The lower hot ductility, the higher sensitivity to surface cracks.

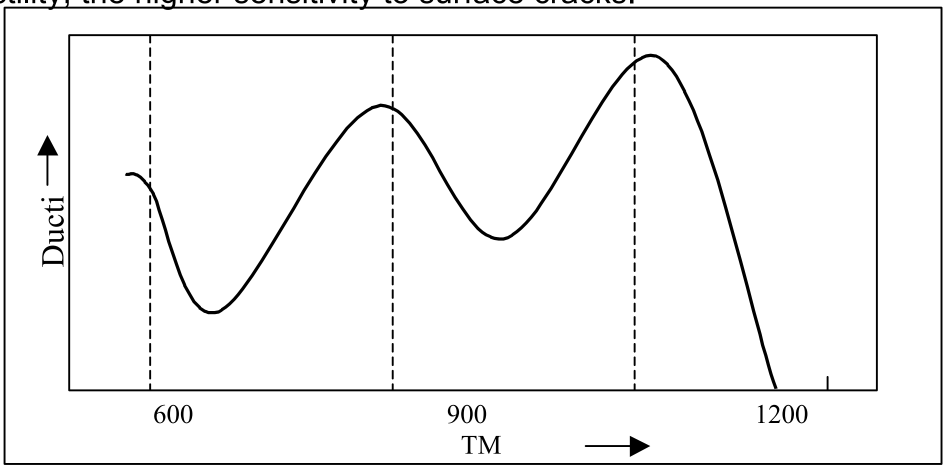

Fig. 4. Schematic representation of ductility troughs appearing in the hot tensile test in steels

2. EXPERIMENTAL PROCEDURES

2.1.Test Design

A 2^2 factorial design was employed to determinate the influence of the two factors under study on the reduction area (RA).

The factors investigated and response variable were the following:

Factors/Levels	Low Level	High Level
Secondary Cooling Water [l/kg]	0.11	0.50
Casting Speed l [m/min]	0.75	0.95

Table 2: Factors applied in the DOE

The four conditions that made up the factorial design are summarized in table 3.

Run Order	casting speed [m/min]	Secondary cooling water [l/kg]
1	0.95	0,11
2	0.75	0.11
3	0.95	0.50
4	0.75	0.50

Table 3. 2^2 DOE Worksheet

Fig. 5 shows the Gleeble specimens geometry used in the hot ductility test. All specimens belong to a single heat and were taken from the mid radius position of a rolled bar.

The idea to vary the secondary cooling water was the change to the amount of heat removed from the bloom during its decent and so, increasing the temperature at the unbending zone of CCM.

The same was doing to the casting speed. The faster the casting speed, the smaller will be the time allowed to the bloom to loose heat by irradiation to the environment. Hence, the higher the casting speed, the higher the temperature at the CCM unbending zone.

Another effect of the casting speed is the fact that it will change the strain rate at the unbending zone. The higher the casting speed, the higher the strain rate and the smaller the susceptibility to surface cracks. Its is believed to happen because there will be (1,2,4):

- insufficient time for strain induced precipitation,
- decrease of grains boundary sliding,

insufficient time for the formation and diffusion controlled growth of void for subsequent precipitation.

The chemical composition of the heat is (%wt):

C	Si	Mn	S	Cr	Ni	V	Al	Nb	B	N
0.16	0.20	1.20	0.030	1.25	0.25	0.025	0.030	0.025	0.002	0.011

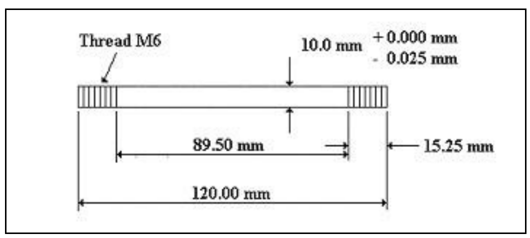

Fig. 5 – Gleeble specimen

Fig.6 shows the computed equivalence between casting speed and strain rates applied on the specimens of the Gleeble CC simulation test, according to the relation ε= +/-100% x ΔR/Rm where:

ε = average deformation rate for two point straightening in our CCM

ΔR=bloom section/2

Rm= machine radius at bloom neutral axis

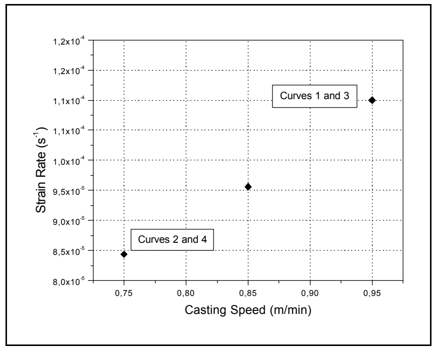

Fig. 6 – Casting Speed x Strain Rate applied in the CCM simulation test

In addition to the temperature profile, the Gleeble machine controls the strain rate at the inner radius surface, simulating the real casting speed.

Figure 7 shows the continuous casting simulation temperature profile in each DOE combination applied by the Gleeble machine. The thermal evolution was computed by a continuos casting mathematical model. The temperature profiles are the ones expected at the bloom near corner surface along the machine.

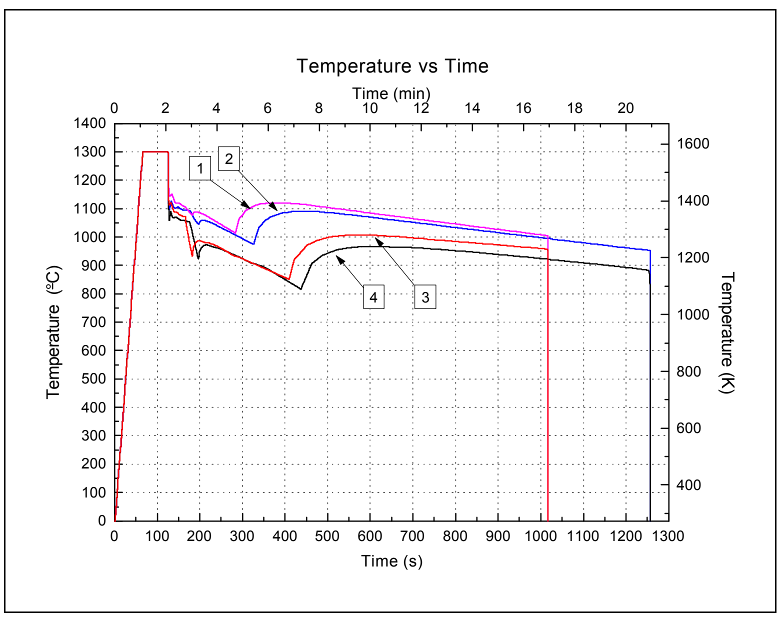

Fig. 7 – Thermal evolution of the casting simulation previous to tensile test

3) Results/Discussion

Figure 8 shows the visual aspect of the specimens after the tests.

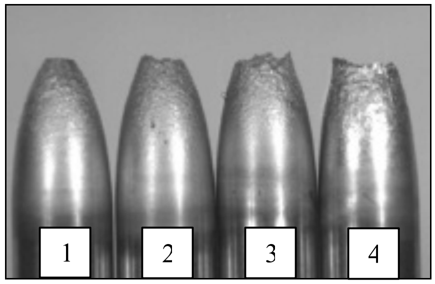

Fig. 8 – visual RA of the specimens after the tests

Figure 9 shows the structure of the fracture after the tests.

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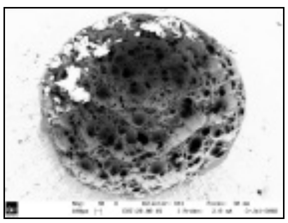
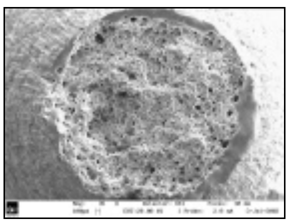
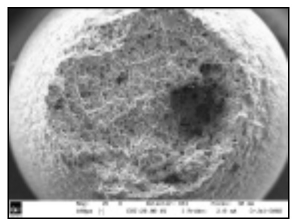
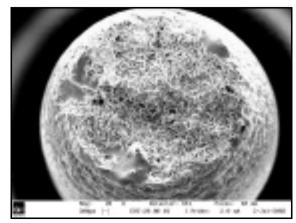
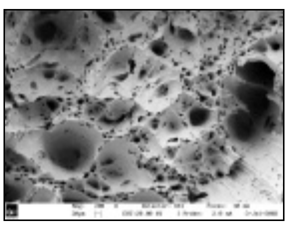
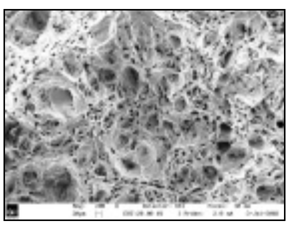
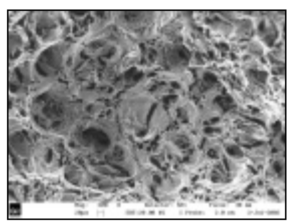
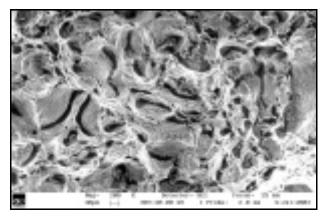
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">1105ºC</td><td colspan="2">1052ºC</td><td colspan="2">1050ºC</td><td colspan="2">993ºC</td></tr>
<tr><td>0,95 m/min</td><td>0,11 l/kg</td><td>0,75 m/min</td><td>0,11 l/kg</td><td>0,95 m/min</td><td>0,50 l/kg</td><td>0,75 m/min</td><td>0,50 l/kg</td></tr>
</table>

Fig. 9. – structure of the specimens after the tests (top=20X, bottom=200X)

Figures 10, 11 and 12 show the hot ductility (%RA) found in the tests were we can see that the RA increases with the casting speed and decreases with the amount of secondary cooling water.

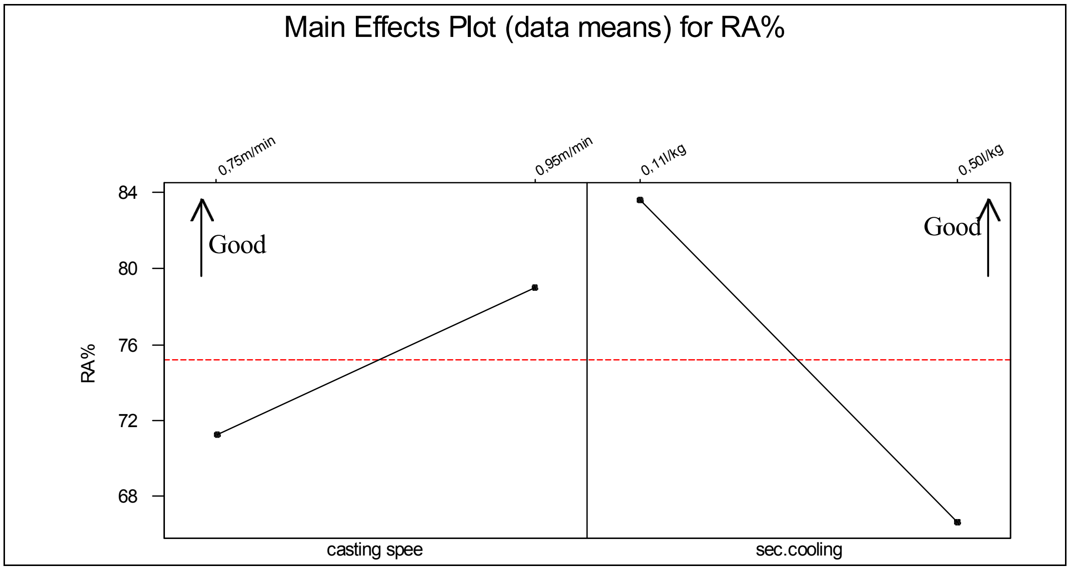

Main Effects Plot (data means) for RA%
0,75m/min
0,95m/min
0,11l/kg
0,50l/kg
84
80
76
72
68
RA%
Good
Good
casting spee
sec.cooling

Fig 10

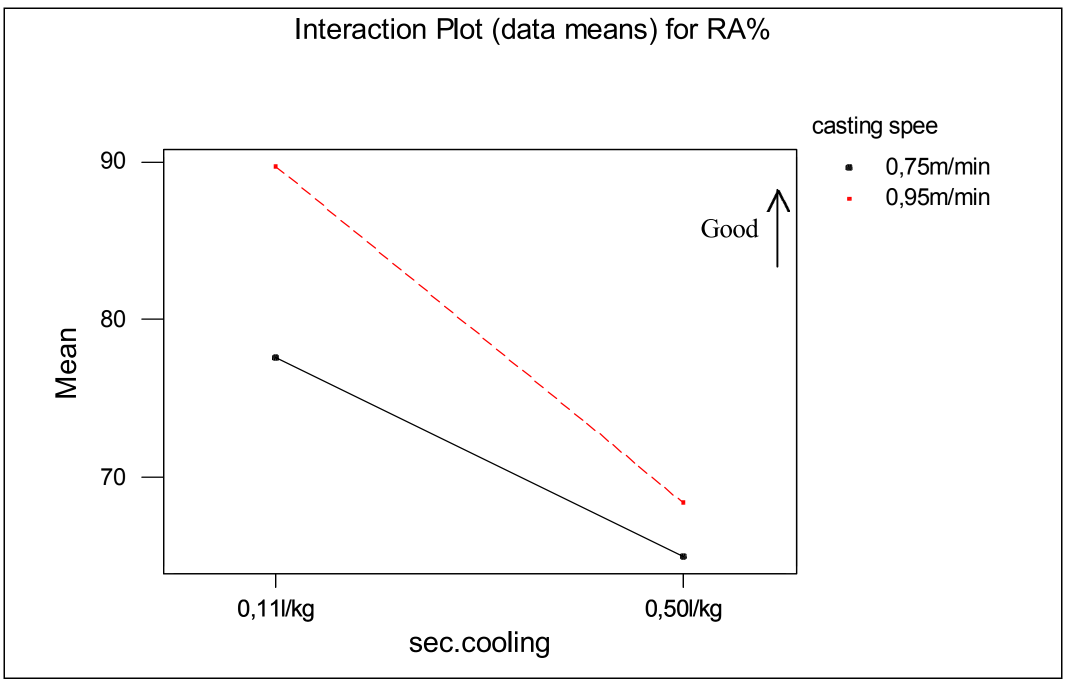

Interaction Plot (data means) for RA%
casting spee
0,75m/min
0,95m/min
90
80
70
Mean
Good
0,11l/kg
0,50l/kg
sec.cooling

Fig 11

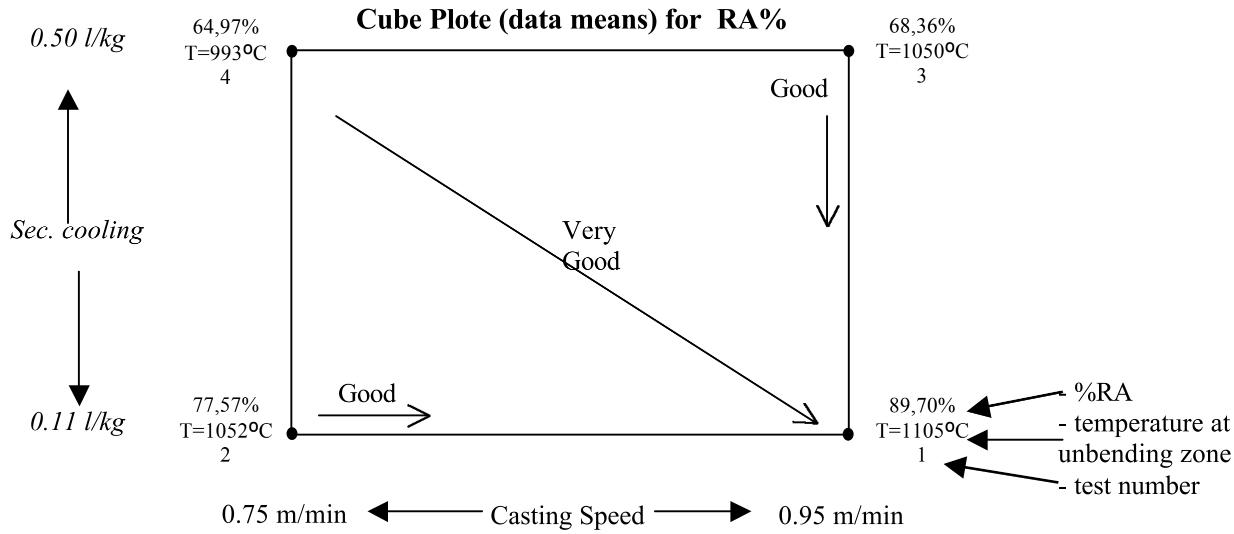


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Fig. 12 Cube Plote for %RA

Changing the temperature at the unbending zone will affect the hot ductility at the most critical zone out of the mould related to the surface cracks.

At higher casting speeds and small secondary cooling water we have got higher hot ductility values and, then, less sensitivity to surface cracks.

This occurs because we will have higher temperatures at bloom surface at the unbending zone.

Additionally, with higher casting speeds we will have higher strain rates and the time to the growing of surface cracks will be reduced.

Even having best results in surface cracks, some side effects can occur using this practice like:

- off corner cracks
- mid face internal cracks
- center cracks

In order to avoid them, foot rollers below the mould are recommended.

These strategy has been applied to the production of these steel and extended to other surface crack problematic steels with great success at Gerdau Aços Finos Piratini.

4) Conclusion:

The 2^2 DOE have shown the following conclusion:

- soft cooling and high casting speeds assure us higher hot ductilities at the most sensitive region apart the mould, thus reducing the tendency to crack formation/growth, as could be checked in the plant results

5) Literature

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