CCC Annual Meeting

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CON1D: Comparison of Microsegregation Models for Weathering Steel (ASTM A588)

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- Introduction
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- Casting Process Scenarios
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- Results: Casting Speed
- Results: Superheat
- Results: Secondary Cooling
- Results: Niobium influence
- Results: Microsegregation EPMA vs CON1D vs DICTRA
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Introduction

Introduction

- **To evaluate the micro-segregation through the CON1D in various conditions of chemical composition and casting process.**

n	Alloy	Vc	SH	Secondary Cooling
	L	**-**	**-**	**-**
1	L	1.25m/min	25ºC	Standard
2	S = 0.025%	1.25m/min	25ºC	Standard
3	L	1.60m/min	25ºC	Standard
4	L	0.84m/min	25ºC	Standard
5	L	1.25m/min	10ºC	Standard
6	L	1.25m/min	35ºC	Standard
7	L	1.25m/min	25ºC	10%
8	L	1.25m/min	25ºC	-10%
9	L	0.99m/min	32.8ºC	Real
10	Nb = 0.020%	1.25m/min	25ºC	Standard
11	Nb = 0.050%	1.25m/min	25ºC	Standard

Process Data: Alloy Design and Casting Parameters

Process Data: Alloy Design and Casting Parameters

- **Alloy Design: According to the table below:**

%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

Process Data: Alloy Design and Casting Parameters

- **Superheat Measured Value: 33,8°C.**
- **Casting Speed: 0,999m/min.**
- **Secondary Cooling: Standard flow values for the slab size and alloy design.**

Casting Process Scenarios

Casting Process Scenarios

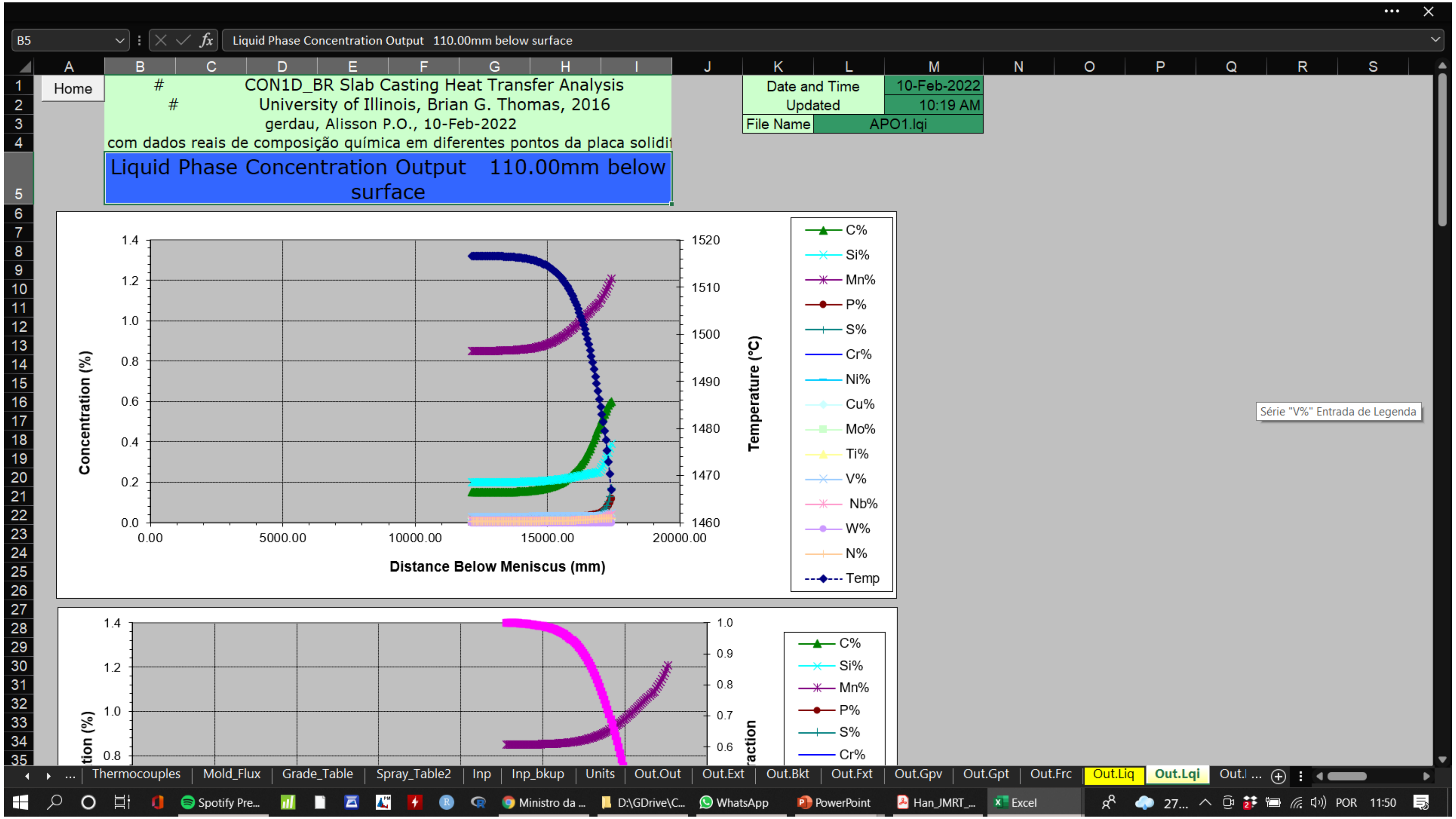
- There are 11 scenarios to be evaluated:
- The default scenario, 1, is as follows:
  - Vc, Casting Speed: 1.25m/min.;
  - SH, Super-Heat: 25°C;
  - Secondary Cooling: Curves for the slab size and alloy design.
- For each chemical composition, a test round will be carried out according to the above scenarios;
- The process 9 relates to the real casting process. This specific slab was used for macro-segregation analysis;
- The processes 10 & 11 are related to Nb variation between 0,020 and 0,050%. The aim is to evaluate the Nb influence on micro-segregation, using three different datasets.

n	Alloy	Vc	SH	Secondary Cooling
	L	-	-	-
1	L	1.25m/min	25ºC	Standard
2	S = 0.025%	1.25m/min	25ºC	Standard
3	L	1.60m/min	25ºC	Standard
4	L	0.84m/min	25ºC	Standard
5	L	1.25m/min	10ºC	Standard
6	L	1.25m/min	35ºC	Standard
7	L	1.25m/min	25ºC	10%
8	L	1.25m/min	25ºC	-10%
9	L	0.99m/min	32.8ºC	Real
10	Nb = 0.020%	1.25m/min	25ºC	Standard
11	Nb = 0.050%	1.25m/min	25ºC	Standard

CON1D output screen for analysis

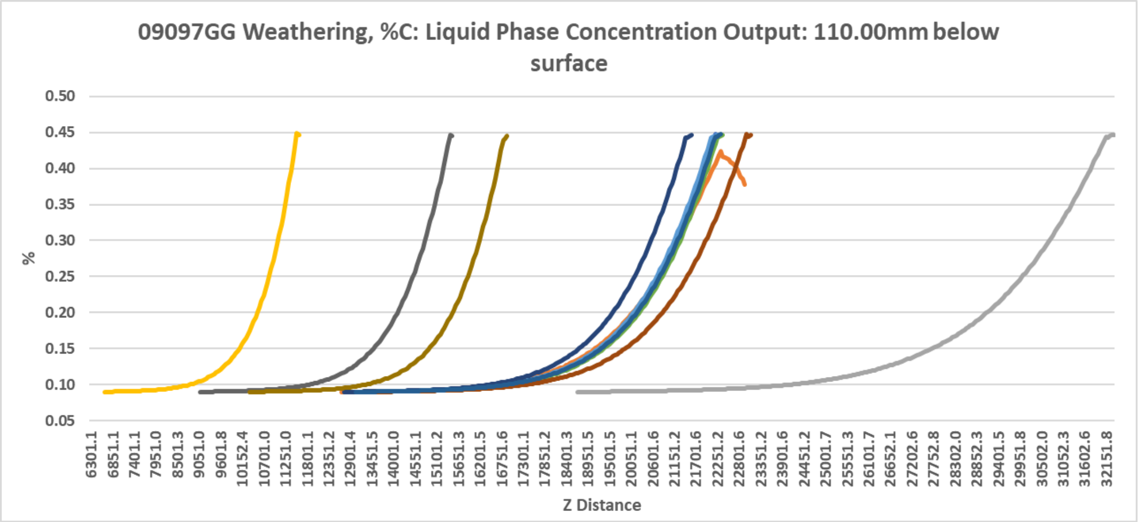
CON1D output screen for analysis

- **As shown below: Out.lqi.**



Microsegregation simulation results

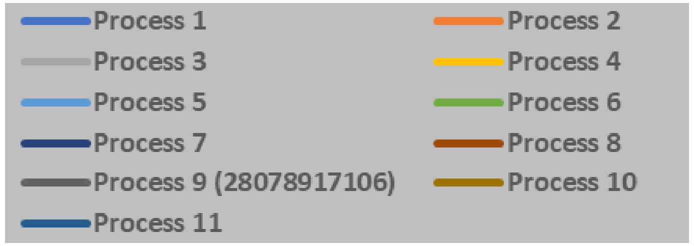
Microsegregation simulation results: %C



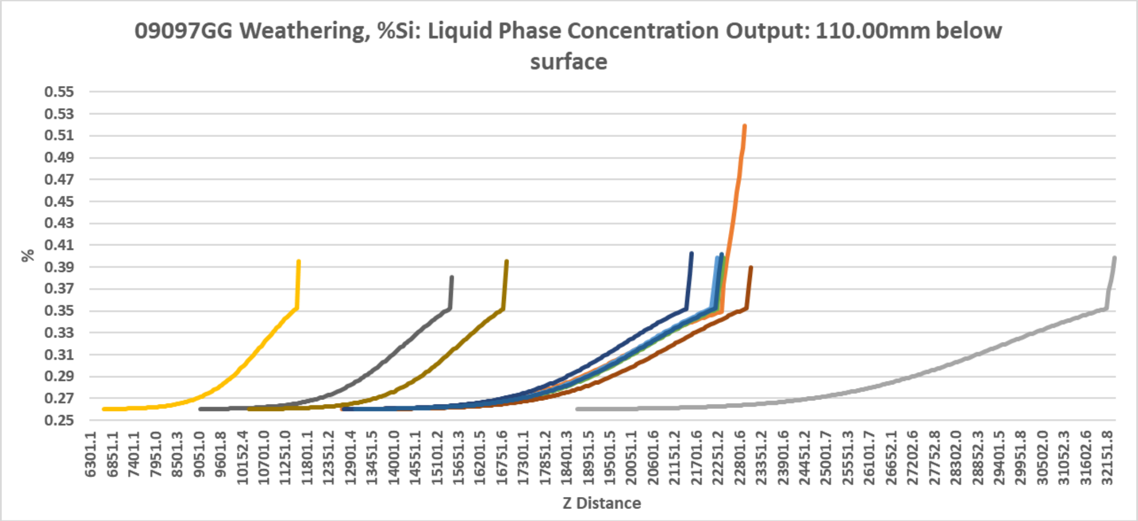
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	Alloy Design	Vc	SH	Secondary Cooling	%C	n
0	L	-	-	-	0.0900	-
1	L	1.25m/min	25ºC	Standard	0.4467	4.963
2	S = 0.025%	1.25m/min	25ºC	Standard	0.3777	4.197
3	L	1.60m/min	25ºC	Standard	0.4470	4.967
4	L	0.84m/min	25ºC	Standard	0.4469	4.966
5	L	1.25m/min	10ºC	Standard	0.4470	4.967
6	L	1.25m/min	35ºC	Standard	0.4470	4.967
7	L	1.25m/min	25ºC	10%	0.4470	4.967
8	L	1.25m/min	25ºC	-10%	0.4464	4.960
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.4454**	**4.949**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	0.4450	4.944
11	Nb = 0.050%	1.25m/min	25ºC	Standard	0.4475	4.972

- **The C micro-segregation variation was minimum between the analyzed processes, except the process 2, with high-S.**
- **The best process to reduce C micro-segregation is the process 2, with high S content. If the Sulphur level is 0,006%, the process 10, with lower Nb content, provides the lower C micro-segregation.**



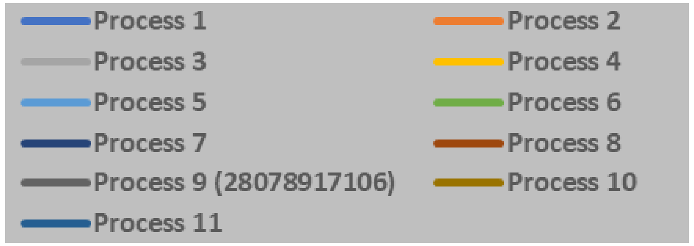
Microsegregation simulation results: %Si



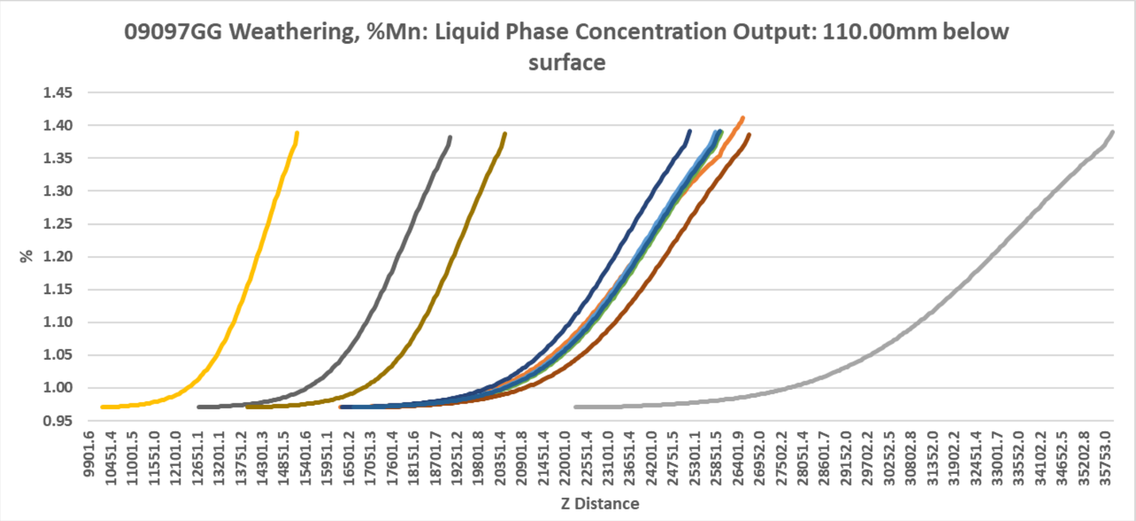
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	Alloy Design	Vc	SH	Secondary Cooling	%Si	n
0	L	-	-	-	0.2600	-
1	L	1.25m/min	25ºC	Standard	0.3925	1.510
2	S = 0.025%	1.25m/min	25ºC	Standard	0.5194	1.998
3	L	1.60m/min	25ºC	Standard	0.3990	1.535
4	L	0.84m/min	25ºC	Standard	0.3957	1.522
5	L	1.25m/min	10ºC	Standard	0.3990	1.535
6	L	1.25m/min	35ºC	Standard	0.3990	1.535
7	L	1.25m/min	25ºC	10%	0.4025	1.548
8	L	1.25m/min	25ºC	-10%	0.3894	1.498
9	L	0.99m/min	32.8ºC	Real	0.3807	1.464
10	Nb = 0.020%	1.25m/min	25ºC	Standard	0.3954	1.521
11	Nb = 0.050%	1.25m/min	25ºC	Standard	0.4016	1.545

- **The best process to reduce Si micro-segregation is the process 9, the real process.**
- **The process 2 presents the higher Si micro-segregation, with the high-S (0,025%). For the low-S, the Si content is reduced from 0,5194 to 0,3925% (Process 1).**
- **The process 7 provides the higher %Si, with low-S, increasing the secondary cooling (-10%).**
- **Si is not strongly influenced by SH neither by Casting Speed. The secondary cooling presents a negative influence when it is increased (+10%).**



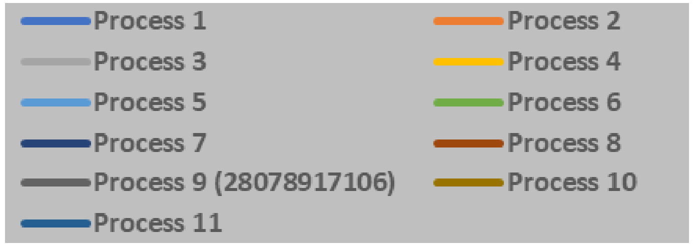
Microsegregation simulation results: %Mn



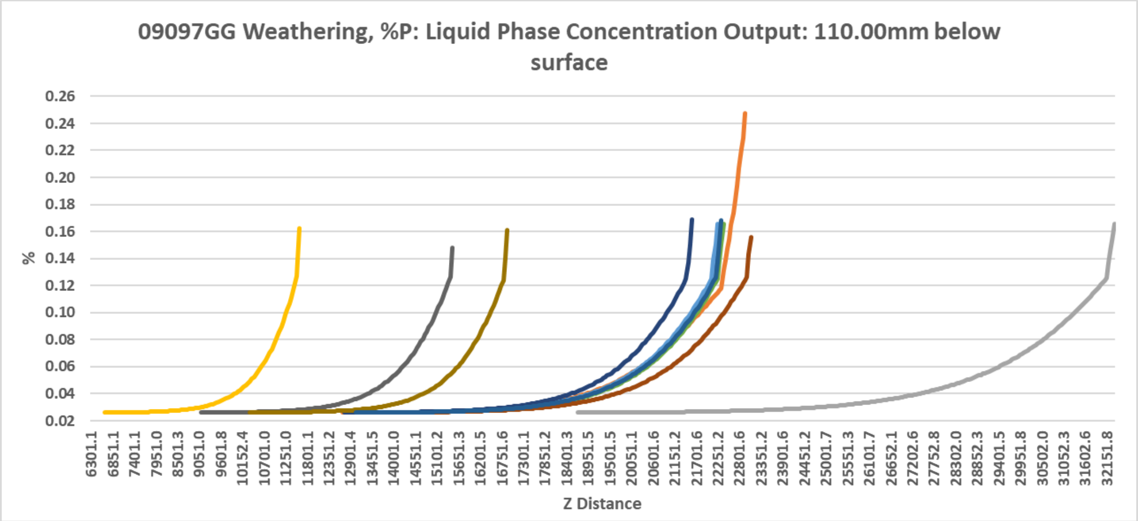
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	Alloy Design	Vc	SH	Secondary Cooling	%Mn	n
0	L	-	-	-	0.9700	-
1	L	1.25m/min	25ºC	Standard	1.3874	1.430
2	S = 0.025%	1.25m/min	25ºC	Standard	1.4116	1.455
3	L	1.60m/min	25ºC	Standard	1.3902	1.433
4	L	0.84m/min	25ºC	Standard	1.3888	1.432
5	L	1.25m/min	10ºC	Standard	1.3902	1.433
6	L	1.25m/min	35ºC	Standard	1.3902	1.433
7	L	1.25m/min	25ºC	10%	1.3917	1.435
8	L	1.25m/min	25ºC	-10%	1.3860	1.429
9	L	0.99m/min	32.8ºC	Real	1.3820	1.425
10	Nb = 0.020%	1.25m/min	25ºC	Standard	1.3881	1.431
11	Nb = 0.050%	1.25m/min	25ºC	Standard	1.3915	1.435

- **The best process to reduce Si micro-segregation is the process 9, the real process.**
- **The process 2 presents the higher Mn micro-segregation, with the high-S (0,025%). For lower Sulphur, the Mn content is reduced from 1,4116 to 1,3874% (Process 1).**
- **The process 7 provides the higher %Si, with low-S, increasing the secondary cooling (-10%).**
- **Mn is not strongly influenced by SH neither by Casting Speed. The secondary cooling presents a negative influence when it is increased (+10%).**



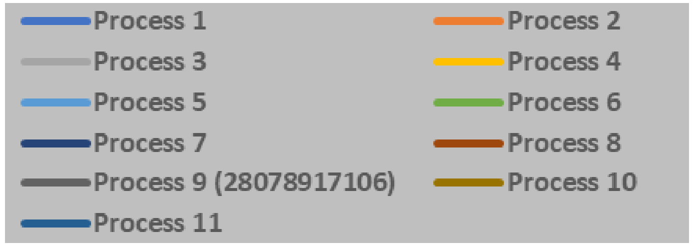
Microsegregation simulation results: %P



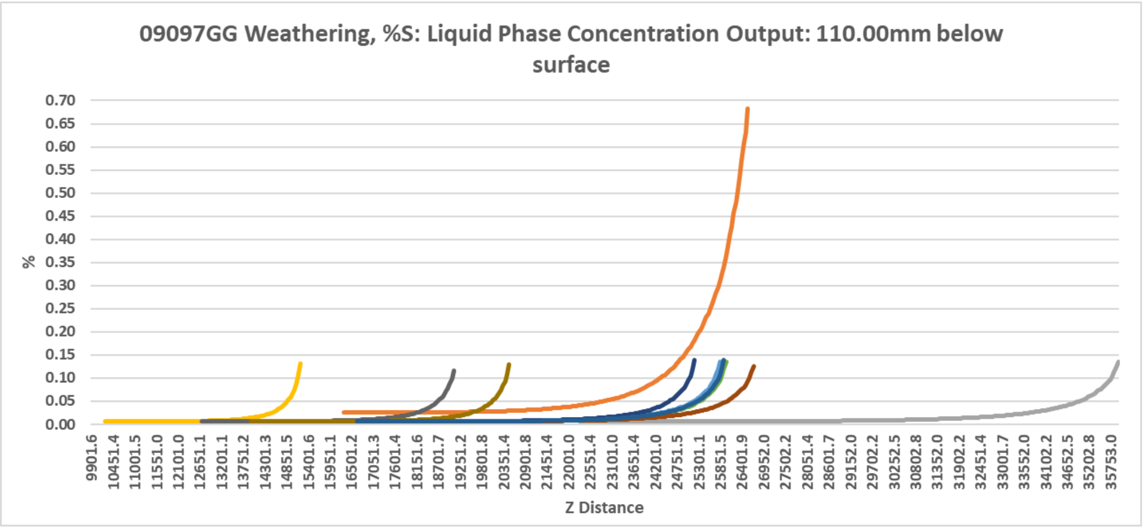
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	**Alloy Design**	**Vc**	**SH**	**Secondary Cooling**	**%P**	**n**
0	**L**	**-**	**-**	**-**	**0.0260**	**-**
1	L	1.25m/min	25ºC	Standard	**0.1590**	6.12
2	S = 0.025%	1.25m/min	25ºC	Standard	**0.2475**	9.52
3	L	1.60m/min	25ºC	Standard	**0.1655**	6.37
4	L	0.84m/min	25ºC	Standard	**0.1621**	6.23
5	L	1.25m/min	10ºC	Standard	**0.1655**	6.37
6	L	1.25m/min	35ºC	Standard	**0.1655**	6.37
7	L	1.25m/min	25ºC	10%	**0.1691**	6.50
8	L	1.25m/min	25ºC	-10%	**0.1559**	6.00
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.1478**	**5.68**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	**0.1611**	6.20
11	Nb = 0.050%	1.25m/min	25ºC	Standard	**0.1684**	6.48

- **The best process to reduce P micro-segregation is the process 9, the real process.**
- **The process 2 presents the higher P micro-segregation, with the high-S (0,025%). For lower Sulphur, the P content is reduced from 0,2475 to 0,1590% (Process 1).**
- **The process 7 provides the higher P micro-segregation, with low-S, increasing the secondary cooling (+10%).**
- **Higher superheat (Process 6) provides a P micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a low P micro-segregation.**



Microsegregation simulation results: %S

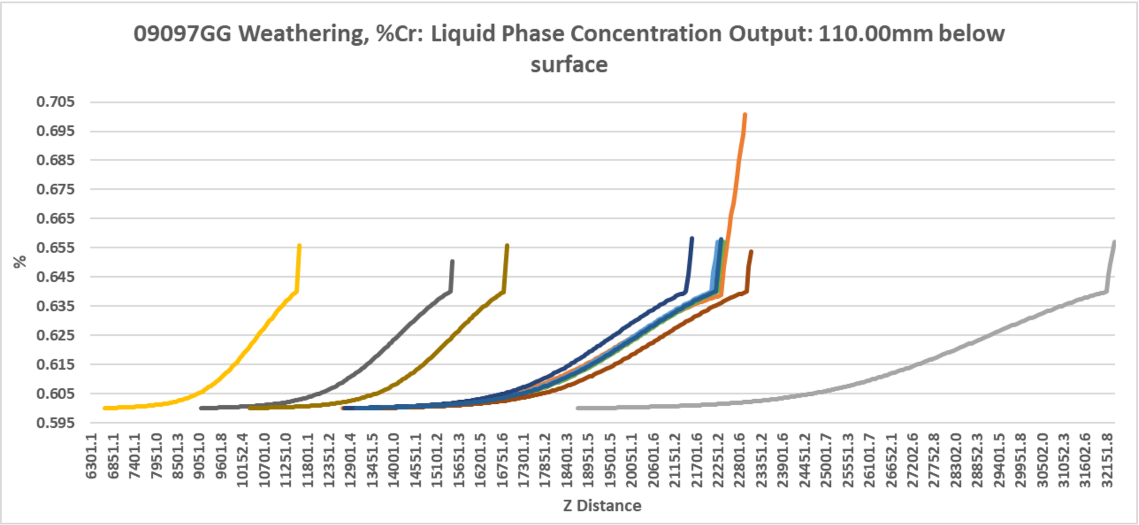


%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	**Alloy Design**	**Vc**	**SH**	**Secondary Cooling**	**%S**	**n**
0	**L**	**-**	**-**	**-**	**0.0060**	**-**
1	L	1.25m/min	25ºC	Standard	**0.1288**	21.47
2	S = 0.025%	1.25m/min	25ºC	Standard	**0.6834**	113.90
3	L	1.60m/min	25ºC	Standard	**0.1359**	22.65
4	L	0.84m/min	25ºC	Standard	**0.1322**	22.03
5	L	1.25m/min	10ºC	Standard	**0.1359**	22.65
6	L	1.25m/min	35ºC	Standard	**0.1359**	22.65
7	L	1.25m/min	25ºC	10%	**0.1398**	23.30
8	L	1.25m/min	25ºC	-10%	**0.1256**	20.93
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.1169**	**19.48**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	**0.1295**	21.58
11	Nb = 0.050%	1.25m/min	25ºC	Standard	**0.1395**	23.25

- **The best process to reduce S micro-segregation is the process 9, the real process.**
- **The process 2 presents the higher S micro-segregation, with the high-S (0,025%). The more S on the heat, the more S micro-segregated.**
- **The process 7 provides the higher S micro-segregation, with low-S, increasing the secondary cooling (+10%).**
- **Higher superheat (Process 6) provides a S micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a low S micro-segregation.**

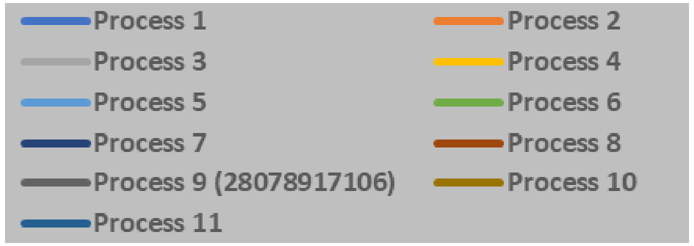
Microsegregation simulation results: %Cr



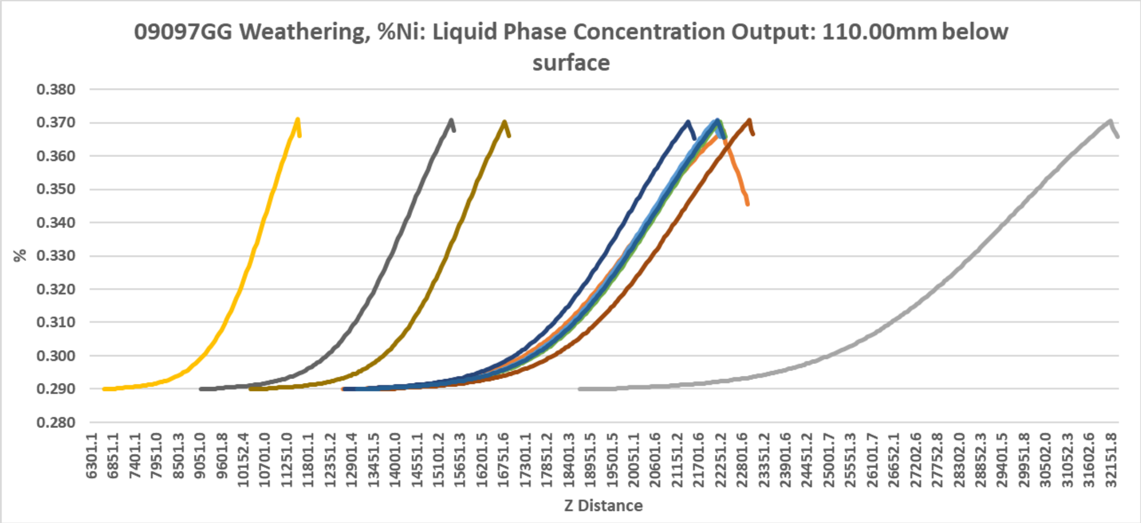
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	**Alloy Design**	**Vc**	**SH**	**Secondary Cooling**	**%Cr**	**n**
0	**L**	**-**	**-**	**-**	**0.6000**	**-**
1	L	1.25m/min	25ºC	Standard	**0.6547**	1.09
2	S = 0.025%	1.25m/min	25ºC	Standard	**0.7009**	1.17
3	L	1.60m/min	25ºC	Standard	**0.6570**	1.10
4	L	0.84m/min	25ºC	Standard	**0.6558**	1.09
5	L	1.25m/min	10ºC	Standard	**0.6570**	1.10
6	L	1.25m/min	35ºC	Standard	**0.6570**	1.10
7	L	1.25m/min	25ºC	10%	**0.6582**	1.10
8	L	1.25m/min	25ºC	-10%	**0.6536**	1.09
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.6505**	**1.08**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	**0.6557**	1.09
11	Nb = 0.050%	1.25m/min	25ºC	Standard	**0.6579**	1.10

- **The best process to reduce Cr micro-segregation is the process 9, the real process.**
- **The process 2 presents the higher Cr micro-segregation, with the high-S (0,025%). For lower-S, the Cr content is reduced (Process 1).**
- **The process 7 provides the higher Cr micro-segregation, with low-S, increasing the secondary cooling (+10%).**
- **Higher superheat (Process 6) provides a Cr micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a low Cr micro-segregation.**



Microsegregation simulation results: %Ni



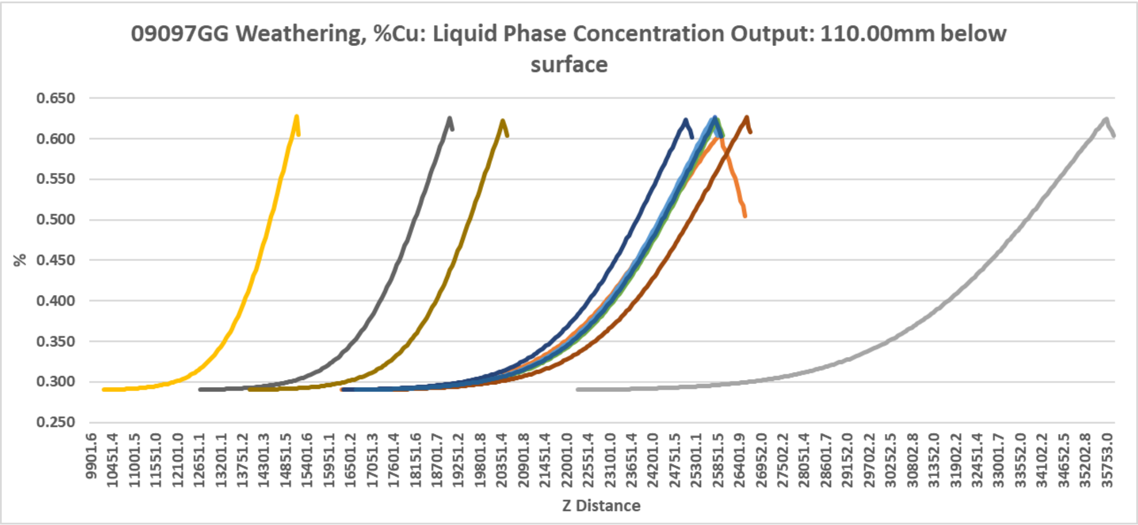
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	**Alloy Design**	**Vc**	**SH**	**Secondary Cooling**	**%Ni**	**n**
0	**L**	**-**	**-**	**-**	**0.2900**	**-**
1	L	1.25m/min	25ºC	Standard	**0.3663**	1.26
2	S = 0.025%	1.25m/min	25ºC	Standard	**0.3456**	1.19
3	L	1.60m/min	25ºC	Standard	**0.3657**	1.26
4	L	0.84m/min	25ºC	Standard	**0.3660**	1.26
5	L	1.25m/min	10ºC	Standard	**0.3657**	1.26
6	L	1.25m/min	35ºC	Standard	**0.3657**	1.26
7	L	1.25m/min	25ºC	10%	**0.3653**	1.26
8	L	1.25m/min	25ºC	-10%	**0.3666**	1.26
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.3675**	**1.27**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	**0.3659**	1.26
11	Nb = 0.050%	1.25m/min	25ºC	Standard	**0.3654**	1.26

- **The best process to reduce Ni micro-segregation is the process 7, with high secondary cooling (+10%) and low-S.**
- **The process 2 presents the lower Ni micro-segregation, with the high-S (0,025%). For low-S the Ni content is increased (Process 1).**
- **Higher superheat (Process 6) provides a Ni micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a high Ni micro-segregation.**

Process 1
Process 2
Process 3
Process 4
Process 5
Process 6
Process 7
Process 8
Process 9 (28078917106)
Process 10
Process 11

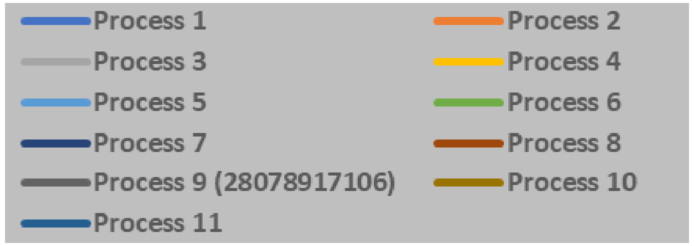
Microsegregation simulation results: %Cu



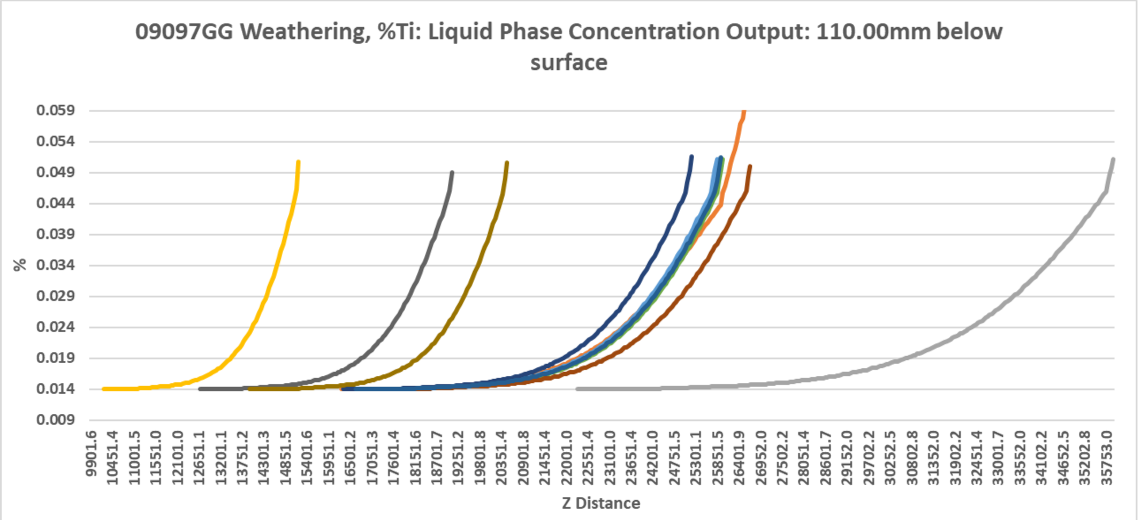
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	Alloy Design	Vc	SH	Secondary Cooling	%Cu	n
0	L	-	-	-	0.2900	-
1	L	1.25m/min	25ºC	Standard	0.6064	2.09
2	S = 0.025%	1.25m/min	25ºC	Standard	0.5044	1.74
3	L	1.60m/min	25ºC	Standard	0.6035	2.08
4	L	0.84m/min	25ºC	Standard	0.6050	2.09
5	L	1.25m/min	10ºC	Standard	0.6035	2.08
6	L	1.25m/min	35ºC	Standard	0.6035	2.08
7	L	1.25m/min	25ºC	10%	0.6019	2.08
8	L	1.25m/min	25ºC	-10%	0.6077	2.10
9	L	0.99m/min	32.8ºC	Real	0.6112	2.11
10	Nb = 0.020%	1.25m/min	25ºC	Standard	0.6042	2.08
11	Nb = 0.050%	1.25m/min	25ºC	Standard	0.6025	2.08

- **The best process to reduce Cu micro-segregation is the process 7, with high secondar cooling (+10%) and low-S.**
- **The process 2 presents the lower Cu micro-segregation, with the high-S (0,025%). For lower Sulphur, the Cu content is increased (Process 1).**
- **Higher superheat (Process 6) provides a Cu micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a high Cu micro-segregation.**



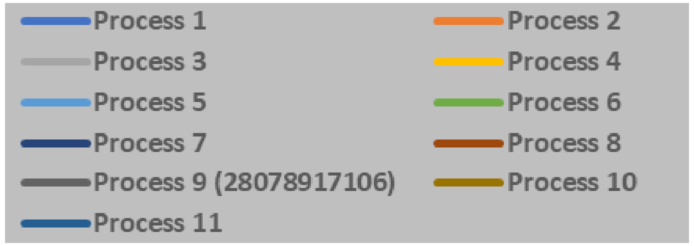
Microsegregation simulation results: %Ti



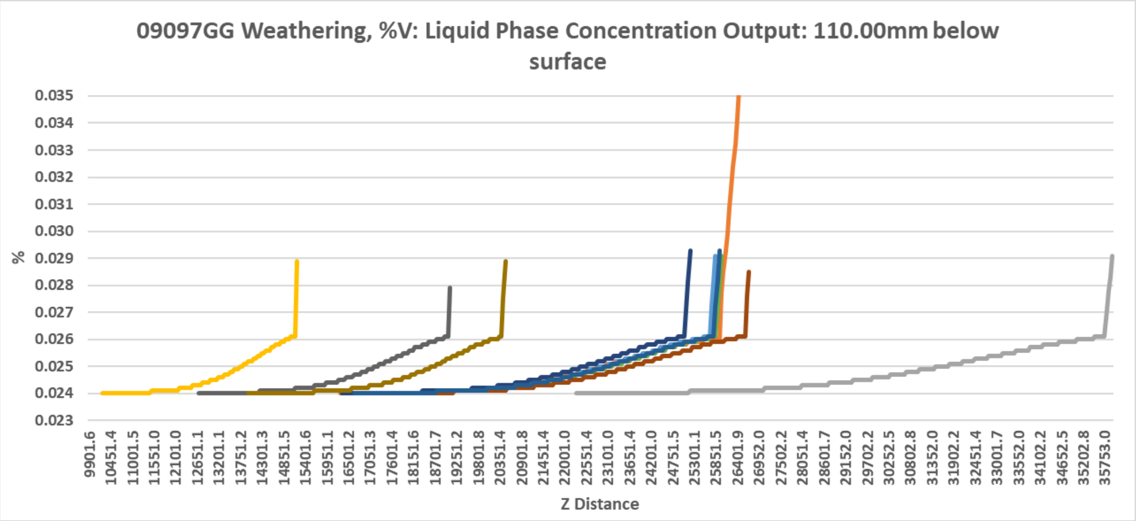
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	**Alloy Design**	**Vc**	**SH**	**Secondary Cooling**	**%Ti**	**n**
0	**L**	**-**	**-**	**-**	**0.0140**	**-**
1	L	1.25m/min	25ºC	Standard	**0.0504**	3.60
2	S = 0.025%	1.25m/min	25ºC	Standard	**0.0597**	4.26
3	L	1.60m/min	25ºC	Standard	**0.0512**	3.66
4	L	0.84m/min	25ºC	Standard	**0.0508**	3.63
5	L	1.25m/min	10ºC	Standard	**0.0512**	3.66
6	L	1.25m/min	35ºC	Standard	**0.0512**	3.66
7	L	1.25m/min	25ºC	10%	**0.0516**	3.69
8	L	1.25m/min	25ºC	-10%	**0.0500**	3.57
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.0490**	**3.50**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	**0.0506**	3.61
11	Nb = 0.050%	1.25m/min	25ºC	Standard	**0.0515**	3.68

- **The best process to reduce Ti micro-segregation is the process 9.**
- **The process 2 presents the higher Ti micro-segregation, with the high-S (0,025%). For low-S, the Ti content is reduced (Process 1).**
- **The process 7 provides the higher Ti micro-segregation, with low-S, increasing the secondary cooling (+10%).**
- **Higher superheat (Process 6) provides a Ti micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a low Ti micro-segregation.**



Microsegregation simulation results: %V



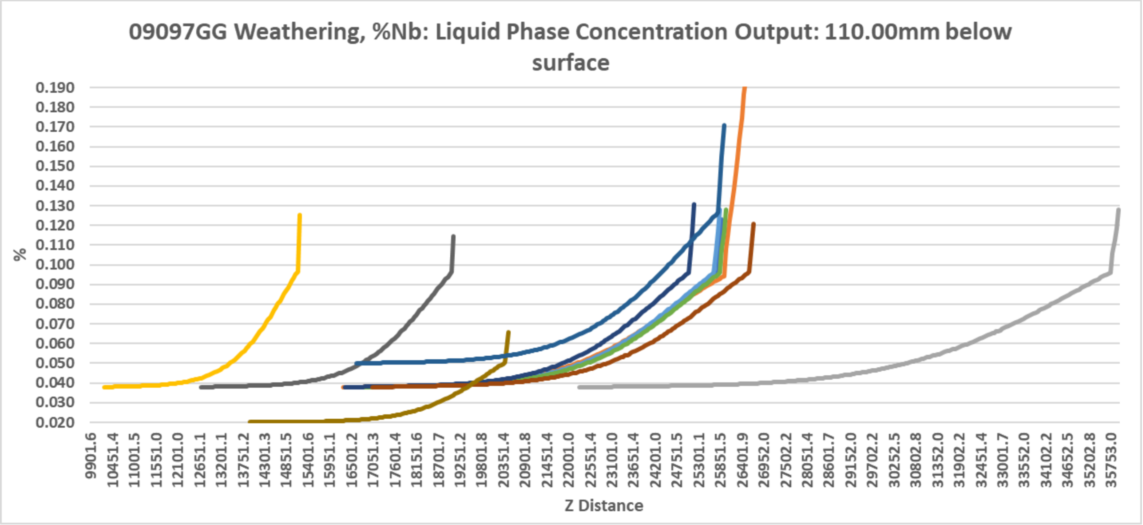
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	Alloy Design	Vc	SH	Secondary Cooling	%V	n
0	L	-	-	-	0.0240	-
1	L	1.25m/min	25ºC	Standard	0.0287	1.20
2	S = 0.025%	1.25m/min	25ºC	Standard	0.0372	1.55
3	L	1.60m/min	25ºC	Standard	0.0291	1.21
4	L	0.84m/min	25ºC	Standard	0.0289	1.20
5	L	1.25m/min	10ºC	Standard	0.0291	1.21
6	L	1.25m/min	35ºC	Standard	0.0291	1.21
7	L	1.25m/min	25ºC	10%	0.0293	1.22
8	L	1.25m/min	25ºC	-10%	0.0285	1.19
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.0279**	**1.16**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	0.0289	1.20
11	Nb = 0.050%	1.25m/min	25ºC	Standard	0.0293	1.22

- **The best process to reduce V micro-segregation is the process 9.**
- **The process 2 presents the higher V micro-segregation, with the high-S (0,025%). For low-S, the V content is reduced (Process 1).**
- **The process 7 provides the higher V micro-segregation, with low-S, increasing the secondary cooling (+10%), together with the high-Nb process.**
- **Higher superheat (Process 6) provides a V micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a low V micro-segregation.**

Process 1 | Process 2 | Process 3 | Process 4 | Process 5 | Process 6 | Process 7 | Process 8 | Process 9 (28078917106) | Process 10 | Process 11

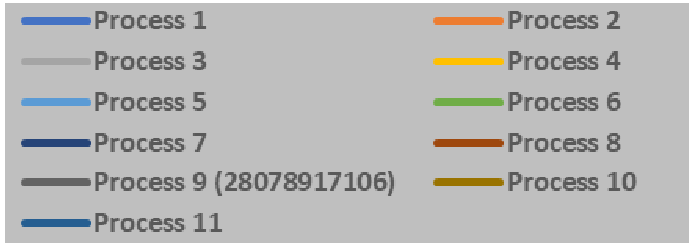
Microsegregation simulation results: %Nb



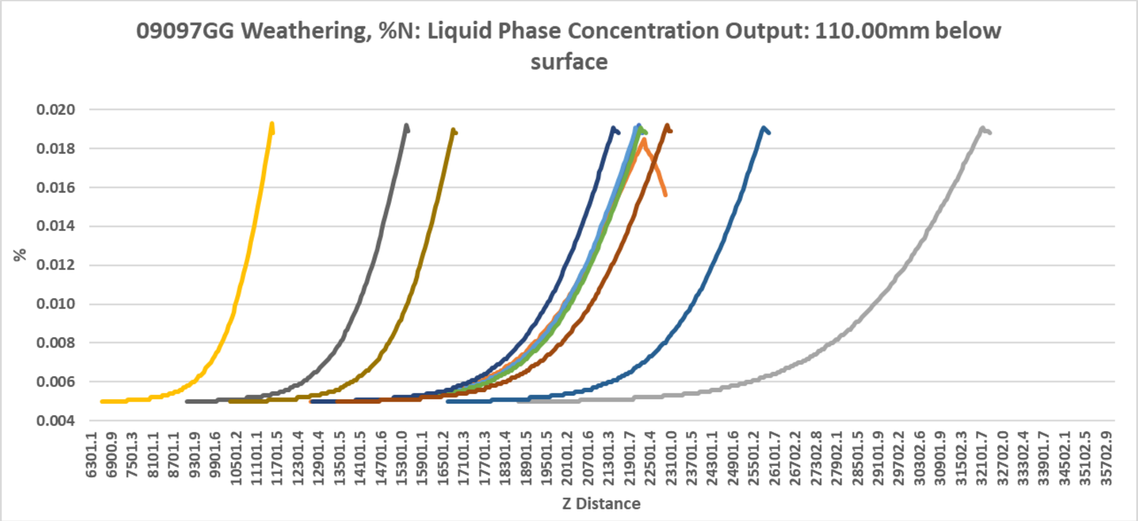
%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	Alloy Design	Vc	SH	Secondary Cooling	%Nb	n
0	L	-	-	-	0.0380	-
1	L	1.25m/min	25ºC	Standard	0.1230	3.24
2	S = 0.025%	1.25m/min	25ºC	Standard	0.2087	5.49
3	L	1.60m/min	25ºC	Standard	0.1279	3.37
4	L	0.84m/min	25ºC	Standard	0.1254	3.30
5	L	1.25m/min	10ºC	Standard	0.1279	3.37
6	L	1.25m/min	35ºC	Standard	0.1279	3.37
7	L	1.25m/min	25ºC	10%	0.1305	3.43
8	L	1.25m/min	25ºC	-10%	0.1207	3.18
9	**L**	**0.99m/min**	**32.8ºC**	**Real**	**0.1145**	**3.01**
10	Nb = 0.020%	1.25m/min	25ºC	Standard	0.0657	1.73
11	Nb = 0.050%	1.25m/min	25ºC	Standard	0.1710	4.50

- **The best process to reduce Nb micro-segregation is the process 9, the real process.**
- **The process 2 presents the higher Nb micro-segregation, with the high-S (0,025%). For low-S, the Nb content is reduced.**
- **The process 7 provides the higher Nb micro-segregation, with low-S, increasing the secondary cooling (+10%).**
- **Higher superheat (Process 6) provides a Nb micro-segregation like that for low superheat (Process 5). An intermediate superheat (Process 1) provides a low Nb micro-segregation.**



Microsegregation simulation results: %N



%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Cu	%Mo	%Ti	%V	%Nb	%N
0.0900	0.2600	0.970	0.026	0.006	0.6000	0.2900	0.2900	0.0030	0.0140	0.0240	0.0380	0.0050

					09097 Weathering	
n	Alloy Design	Vc	SH	Secondary Cooling	%N	n
0	L	-	-	-	0.0050	-
1	L	1.25m/min	25ºC	Standard	0.0188	3.76
2	S = 0.025%	1.25m/min	25ºC	Standard	0.0156	3.12
3	L	1.60m/min	25ºC	Standard	0.0188	3.76
4	L	0.84m/min	25ºC	Standard	0.0188	3.76
5	L	1.25m/min	10ºC	Standard	0.0188	3.76
6	L	1.25m/min	35ºC	Standard	0.0188	3.76
7	L	1.25m/min	25ºC	10%	0.0188	3.76
8	L	1.25m/min	25ºC	-10%	0.0189	3.78
9	L	0.99m/min	32.8ºC	Real	0.0189	3.78
10	Nb = 0.020%	1.25m/min	25ºC	Standard	0.0188	3.76
11	Nb = 0.050%	1.25m/min	25ºC	Standard	0.0188	3.76

- **The best process to reduce N micro-segregation is the process 2, with high-S.**
- **The process 8 and 9 provides equal values for N segregation. The other process provides also equal values.**

Process 1 | Process 2 | Process 3 | Process 4 | Process 5 | Process 6 | Process 7 | Process 8 | Process 9 (28078917106) | Process 10 | Process 11

Results: Process Comparisons

Results: Process Comparisons

- **According to the tables below:**

Best process	
Chemical element	**09097 Weathering**
C	2 (10)
Si	9
Mn	9
P	9
S	9
Cr	9
Ni	2 (7)
Cu	2 (7)
Mo	-
Ti	9
V	9
Nb	9
N	2 (1, 4, 5, 6, 7, 10, 11)

Worst process	
Chemical element	**09097 Weathering**
C	11
Si	2 (7)
Mn	2 (7)
P	2 (7)
S	2 (7)
Cr	2 (7)
Ni	9
Cu	9
Mo	-
Ti	2 (7)
V	2 (7)
Nb	2 (7)
N	9

n	Alloy	Vc	SH	Secondary Cooling
1	L	1.25m/min	25ºC	Standard
2	S = 0.025%	1.25m/min	25ºC	Standard
3	L	1.60m/min	25ºC	Standard
4	L	0.84m/min	25ºC	Standard
5	L	1.25m/min	10ºC	Standard
6	L	1.25m/min	35ºC	Standard
7	L	1.25m/min	25ºC	10%
8	L	1.25m/min	25ºC	-10%
9	L	0.99m/min	32.8ºC	Real
10	Nb = 0.020%	1.25m/min	25ºC	Standard
11	Nb = 0.050%	1.25m/min	25ºC	Standard

- **For each chemical element there is a process condition which allows a lower (best process) or higher (worst process) level of micro-segregation under the conditions evaluated, according to CON1D.**
- **Best casting process:**
  - **For most of the chemical elements evaluated (Si, Mn, P, S, Cr, Ti, V, Nb) the process 9 proved to be the most suitable to reduce the level of micro-segregation.**
  - **C, Ni Cu and N share process 2 (Steel with higher S) to obtain less micro-segregation. In parentheses the alternative processes to avoid the high-S content.**

Results: Process Comparisons

- According to the tables below:

Best process	
Chemical element	09097 Weathering
C	2 (10)
Si	9
Mn	9
P	9
S	9
Cr	9
Ni	2 (7)
Cu	2 (7)
Mo	-
Ti	9
V	9
Nb	9
N	2 (1, 4, 5, 6, 7, 10, 11)

Worst process	
Chemical element	09097 Weathering
C	11
Si	2 (7)
Mn	2 (7)
P	2 (7)
S	2 (7)
Cr	2 (7)
Ni	9
Cu	9
Mo	-
Ti	2 (7)
V	2 (7)
Nb	2 (7)
N	9

n	Alloy	Vc	SH	Secondary Cooling
1	L	1.25m/min	25ºC	Standard
2	S = 0.025%	1.25m/min	25ºC	Standard
3	L	1.60m/min	25ºC	Standard
4	L	0.84m/min	25ºC	Standard
5	L	1.25m/min	10ºC	Standard
6	L	1.25m/min	35ºC	Standard
7	L	1.25m/min	25ºC	10%
8	L	1.25m/min	25ºC	-10%
9	L	0.99m/min	32.8ºC	Real
10	Nb = 0.020%	1.25m/min	25ºC	Standard
11	Nb = 0.050%	1.25m/min	25ºC	Standard

- Worst casting process:
  - For most of the chemical elements evaluated (Si, Mn, P, Cr, Ti, V, Nb) the process 2 (High-S) proved to be the most suitable to increase the level of micro-segregation.
  - For carbon the process 11, high-Nb, presented the high content for the carbon segregation.
  - Ni Cu and N share process 9 to obtain high element micro-segregation. In parentheses the worst process in the case of lower Sulphur content.

Results: Casting Speed

Results: Casting Speed

Alisson Paulo de Oliveira

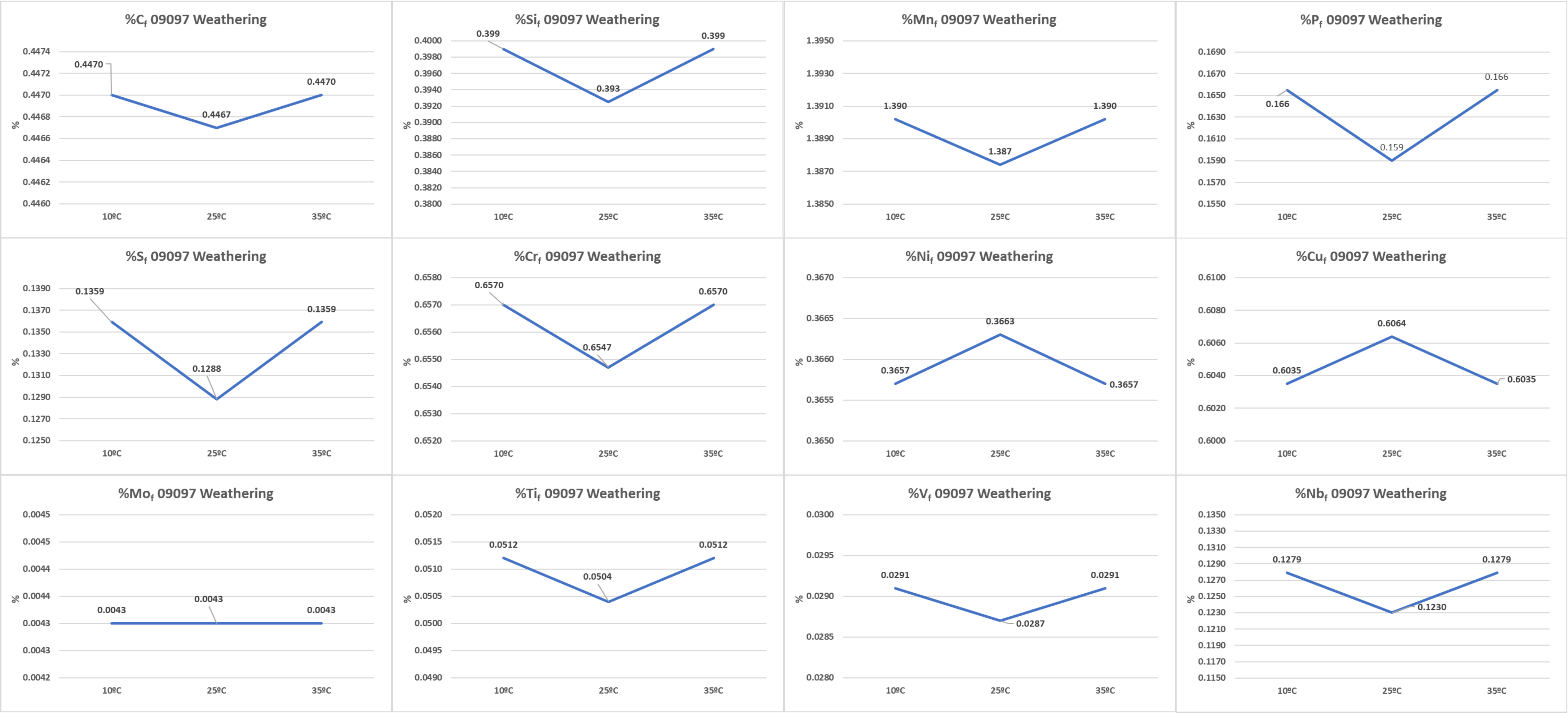
Results: Casting Speed

- **For most of the chemical elements analyzed, a micro-segregation peak can be seen for a speed of 1.60 m/min. The exceptions are Ni and Cu, where micro-segregation reaches a minimum for this casting speed.**

- **Mo and N presents no influence from Vc on micro-segregation.**

Results: Superheat

Results: Superheat

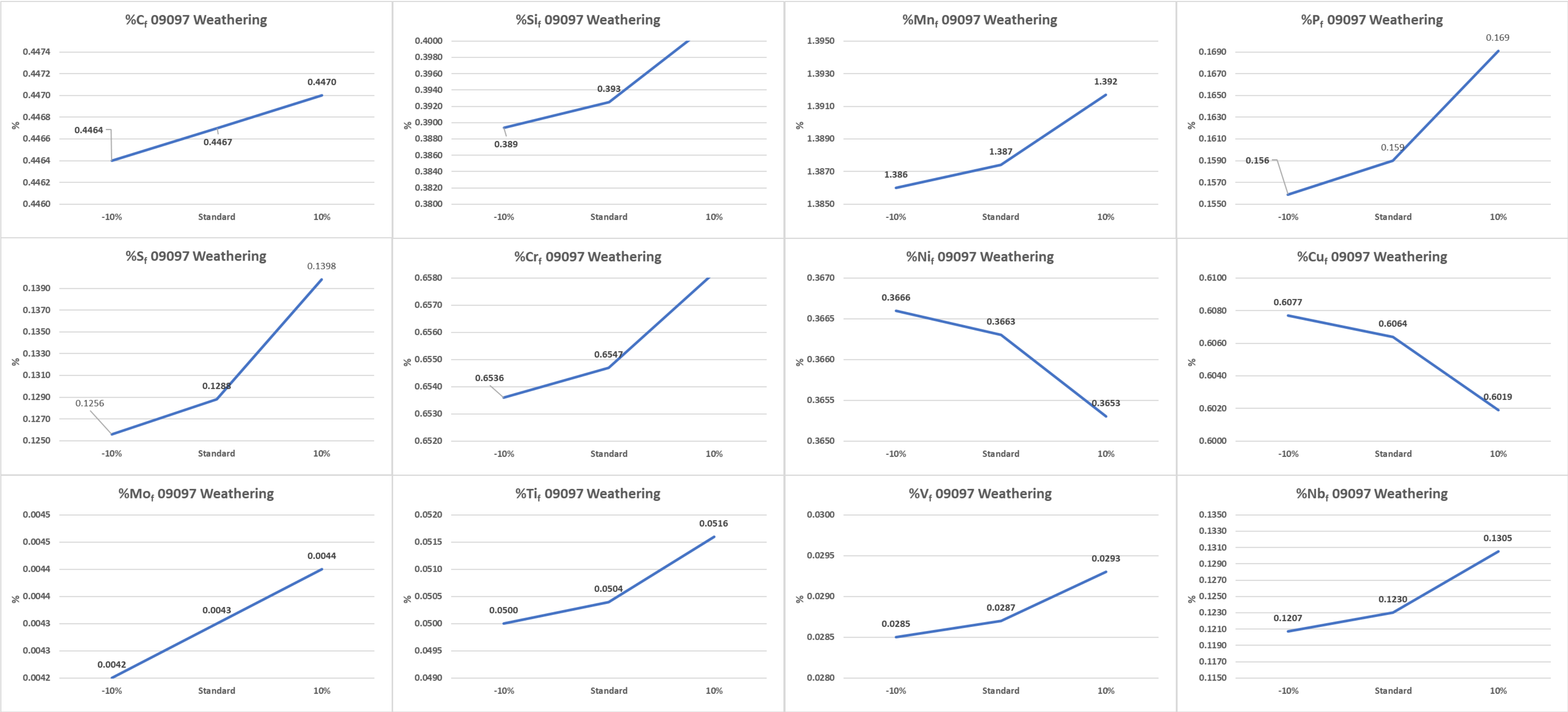


Results: Superheat

- **For most of the chemical elements analyzed, an intermediate superheat can reduce the level of micro-segregation. The exceptions are Ni and Cu.**

Results: Secondary Cooling

Results: Secondary Cooling



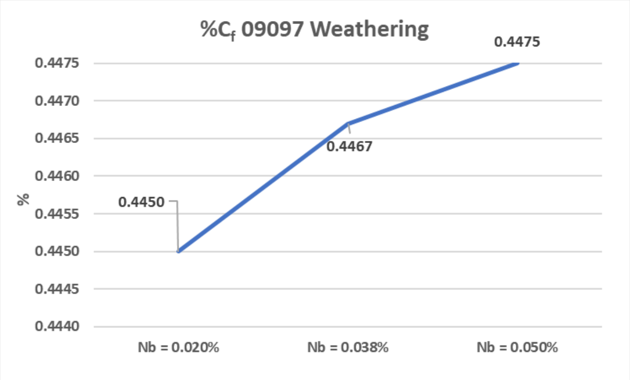
Results: Secondary Cooling

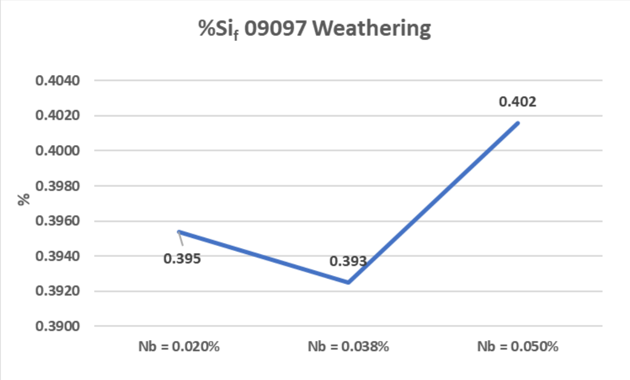
- For most of the chemical elements analyzed, higher cooling can reduce the level of micro-segregation. The exceptions are Ni, Cu and N.

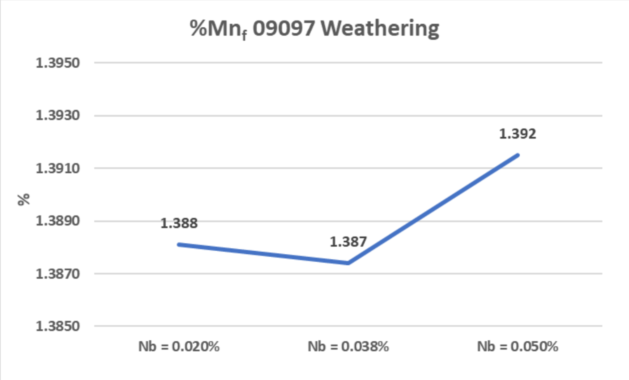
- If compared to the other key parameters, the secondary cooling looks to have a more pronounced influence on the micro-segregation.

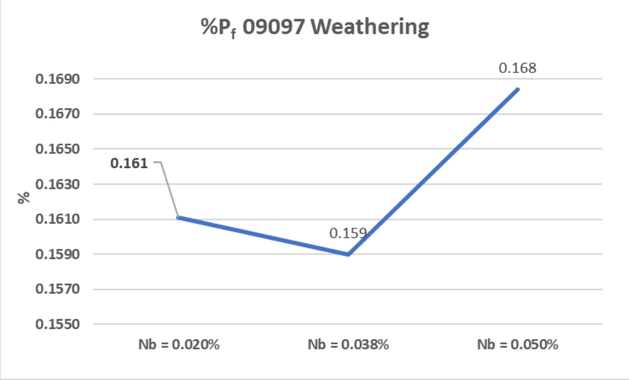
Results: Niobium influence

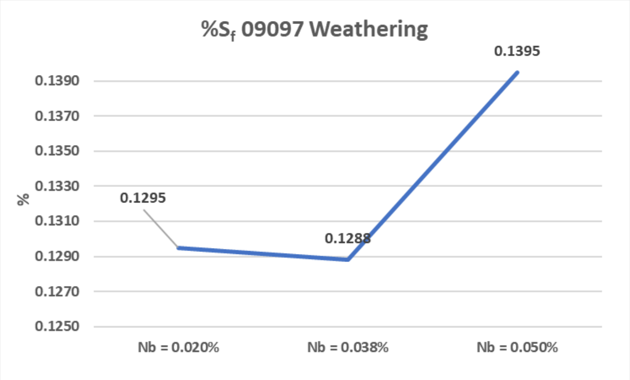
Results: Niobium influence

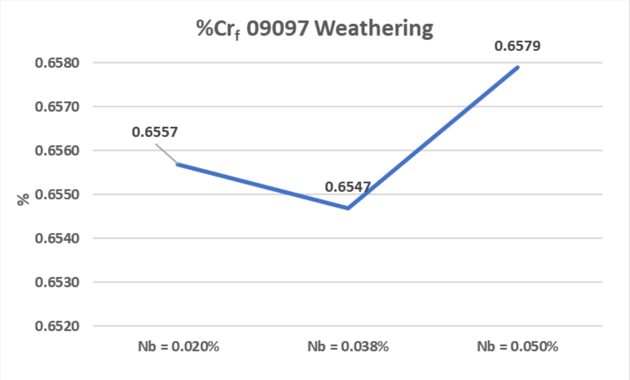


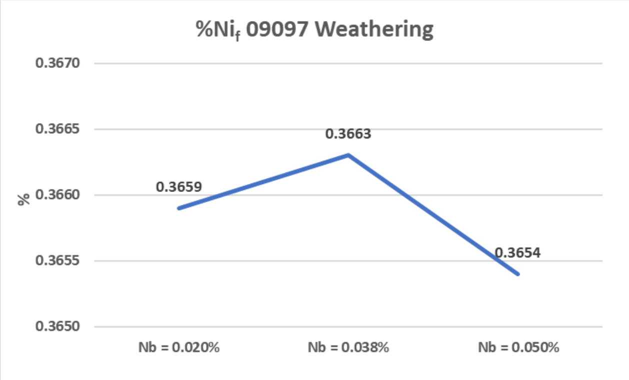


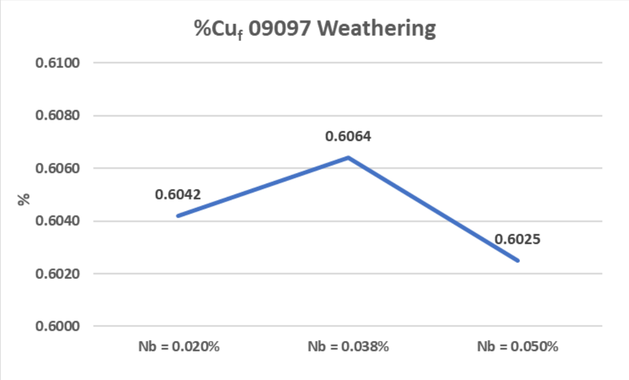


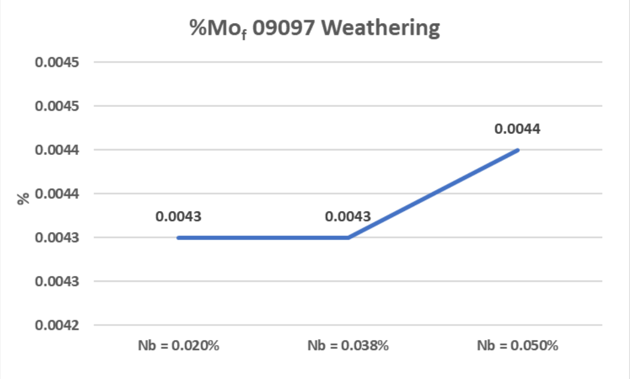


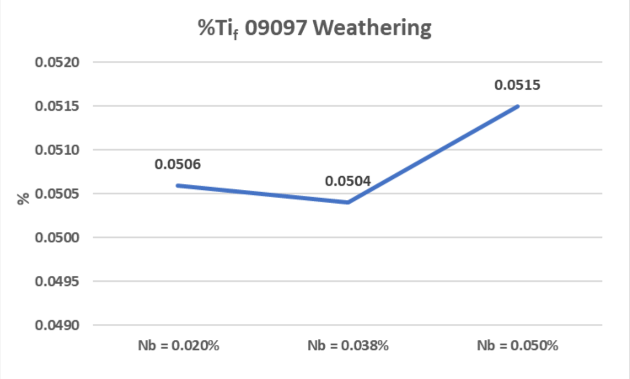


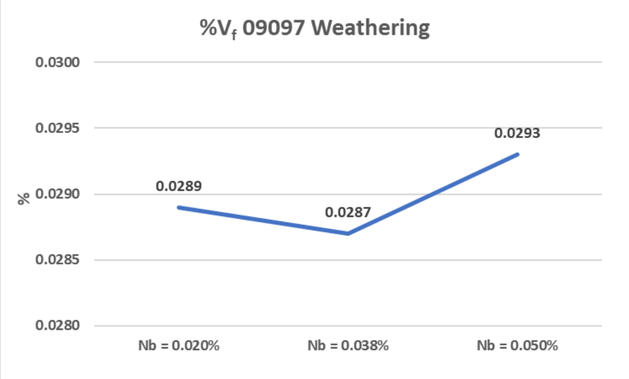


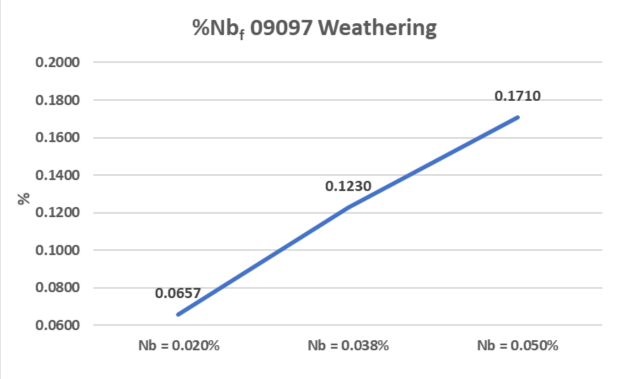












Results: Niobium influence

- According to CON1D, the Niobium influences the micro-segregation of chemical elements, increasing or reducing it, in different ways.

- The increase of Nb content, from 0,020 to 0,038% appears to decrease the micro-segregation for most of the elements: Si, Mn, P, S, Cr, Ti, V. The exceptions are C, Ni and Cu.

- The increase of Nb content, from 0,038 to 0,050% appears to increase the micro-segregation for most of the elements: C, Si, Mn, P, S, Cr, Mo, Ti, V. The exceptions are Ni and Cu.

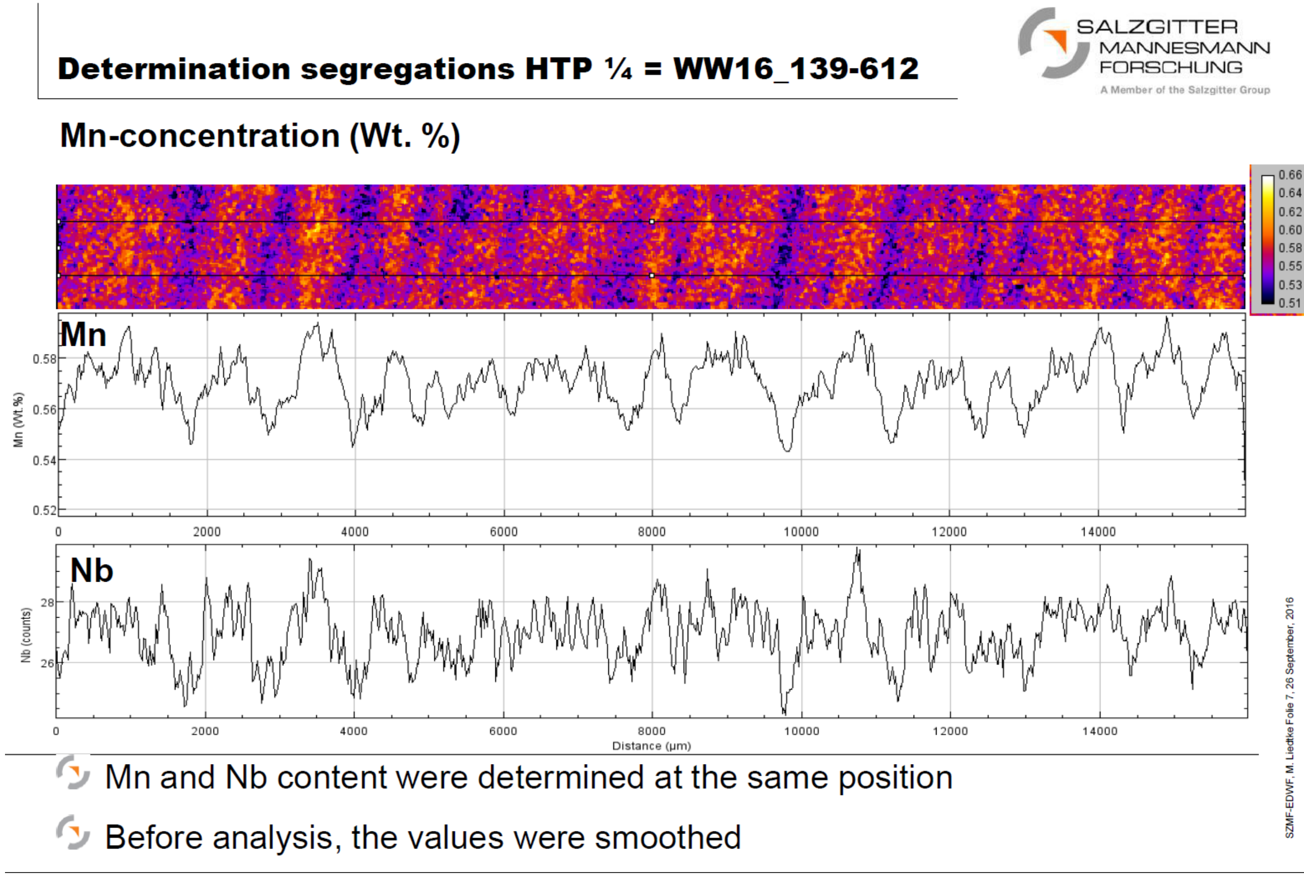
Results: Microsegregation EPMA vs CON1D vs DICTRA

Results: Microsegregation EPMA vs CON1D vs DICTRA

- Two steel samples with a size of 20 x 20 mm each were delivered to SZMF.
- For both samples, the distribution of Mn and Nb was analyzed by microprobe on the transversal plane. Mn was analyzed quantitatively and Nb was analyzed qualitatively.
- The Mn value, analyzed by EPMA technique on the Research Center of Salzgitter and the DICTRA simulation were the following:

Analysis/Simulation	A588, %Mn	
	Rich region	Poor region
SalzGitter	1.500	0.900
Dictra	1.550	0.878
CON1D_BR	1.383	

- The CON1D simulates the Mn content at the interface L/S with good precision (-7,8%) if compared with the real value, determined by EPMA.



Conclusions

Conclusions

- The CON1D allowed the analysis of the influence of different process scenarios on the micro-segregation of chemical elements in a real, weatherable HSLA steel, produced according to ASTM A588.
- It was possible to establish the best, and worst, process aiming the lowest micro-segregation of a specific chemical element that is deleterious for product feature that is desired to increase the steel quality.
- The search for better toughness forces the choice of a process that provides less micro-segregation of chemical elements of interest, for example.
- The process 9, the real process, is the one that provided, according to CON1D, the lower micro-segregation for most chemical elements. Processes 2 and 7 should be avoided for most situations.
- Real values of Mn (rich area) taken from EPMA analysis shows a minor difference if compared with the last calculated Mn value (the CON1D), at S/L interface: -7,8%.
- If compared with DICTRA, an interdendritic Mn content analysis, the difference is equal to -10,77% (rich area).
- For a correct understanding of how the model calculates the segregated contents of each chemical element and the apparent interaction of other elements (S, Mn) it would be interesting to search in the source code for the general equation and assess what is influencing these results.
- The results show that CON1D can be used for parametric studies to determine the best production process considering numerous scenarios.

Acknowledgments

Acknowledgments

- Continuous Casting Consortium/Center Members (Cleveland Cliffs, CBMM, Evraz, JFE Steel Corp., RHI Magnesita, Nucor Steel, Posco/Pukyong, SSAB, Tata Steel, USS, ANSYS/ Fluent).
- Gerdau Ouro Branco for kindly sharing its Slab CC process data that allowed to perform this study.