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DI METALLURGIA

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PROCESS MODEL FOR SECONDARY METALLURGY

AIM contribution on process modeling in RFCS projects

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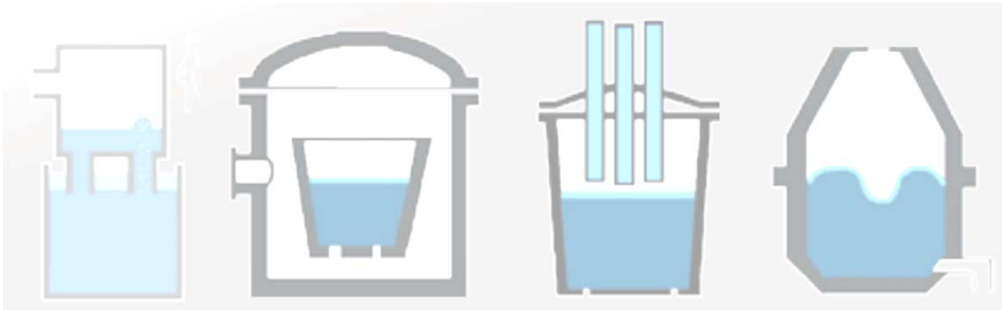
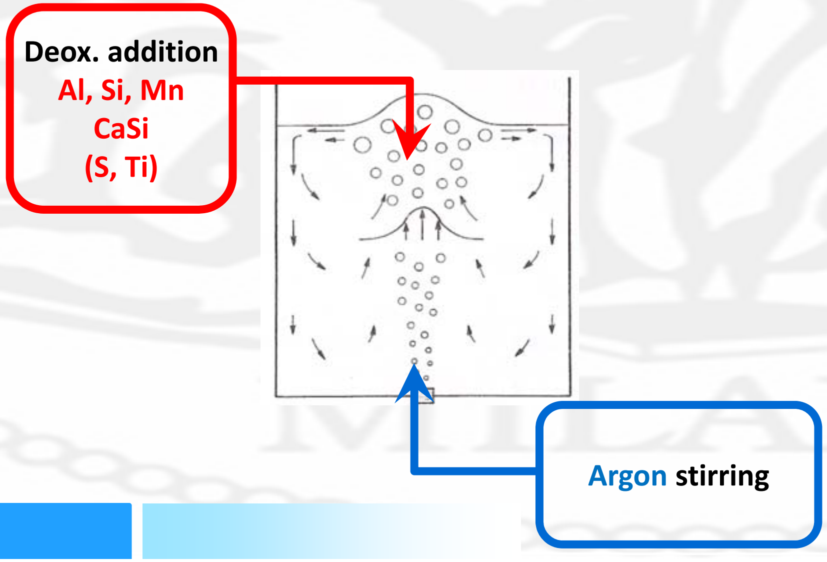


PREVISION OF INCLUSIONAL CONTENT IN STRUCTURAL STEEL

Main goals

1. AIMS: set-up a computational model able to:
    1. predict inclusional content
    2. predict size distribution of non-metallic inclusions

2. The model allows to define:
    1. evolution of the inclusions average size during different stages of the ladle refining
    2. inclusions final size and distribution by modeling formation, growth and removal mechanisms



Model set-up

Considered mechanism

1. inclusions growth by collision phenomena
2. clearing by flotation thorough argon stirring

Hypothesis

A. steel bath
   1. steel is an uncompressible Newtonian turbulent fluid
   2. slag fluid-dynamic motion are not considered
   3. argon flux is directed to the bath surface without fluctuation
   4. heat convection is not considered

B. argon bubbles
   1. maintain the same dimension
   2. are spherical and not deformable
   3. interaction between bubbles are not considered

C. non-metallic inclusions
   1. are spherical and uniform distributed inside the bath
   2. inclusion dimension not affect the fluid-dynamic of steel bath

Inclusions growth by collision

simultaneous collisions → average size growth

Collision frequency equations β^n [m³/s]

1. Saffman-Turner

$$\beta_{ij}^{T} = 1.3\sqrt{\pi}\alpha_t\left(\frac{\varepsilon}{\nu_L}\right)^{0,5}\left(r_i + r_j\right)^3$$

2. Brown

$$\beta_{ij}^{B} = \frac{2}{3}\frac{k_B T}{\mu_L}\left(r_i + r_j\right)\left(\frac{1}{r_i} + \frac{1}{r_j}\right)$$

3. Stokes

$$\beta_{ij}^{S} = \frac{2\pi g\left(\rho_L - \rho_P\right)}{9\mu_L}\left|r_i - r_j\right|\left(r_i + r_j\right)^3$$

Inclusions growth by collision

simultaneous collisions → **average size growth**

Collision frequency equations β^n [m³/s]

1. Saffman-Turner

$$\beta^T = 1.3\alpha_t\sqrt{\pi}\left(\frac{\varepsilon}{\nu}\right)^{0,5}(2\mu+\sigma)^3$$

2. Brown

$$\beta^B = \frac{2}{3}\frac{k_B T}{\mu_L}2\left(1+\frac{1}{\mu+\sigma}\right)$$

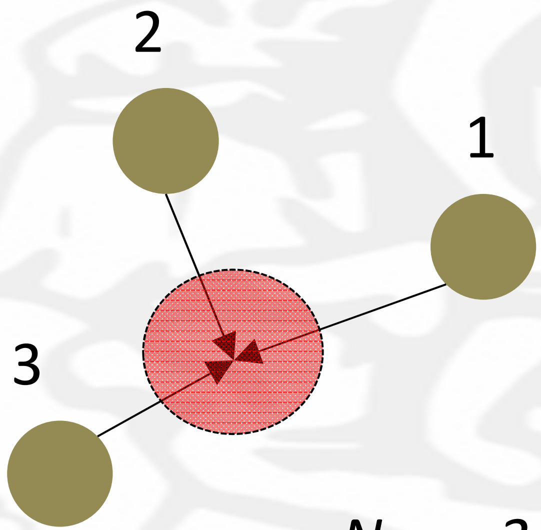
3. Stokes

null for particles with same radius

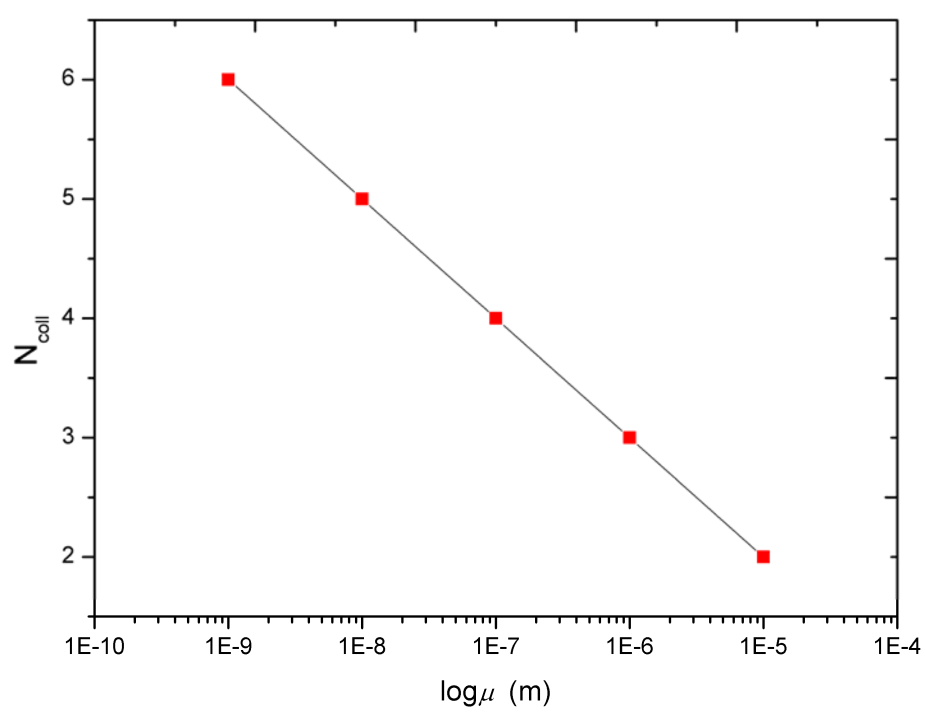
Inclusions growth by collision

simultaneous collision probability

$$P_{coll} = \frac{1}{3 \cdot N_{coll}!}$$



es. $N_{coll} = 3$



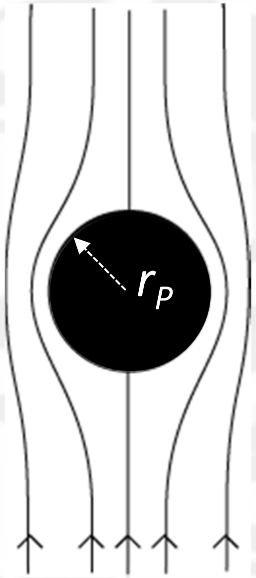
$$N_{coll} = -0,434\ln(\mu) - 1$$

Clearing by floatation

floatation contribution

Stokes floating velocity

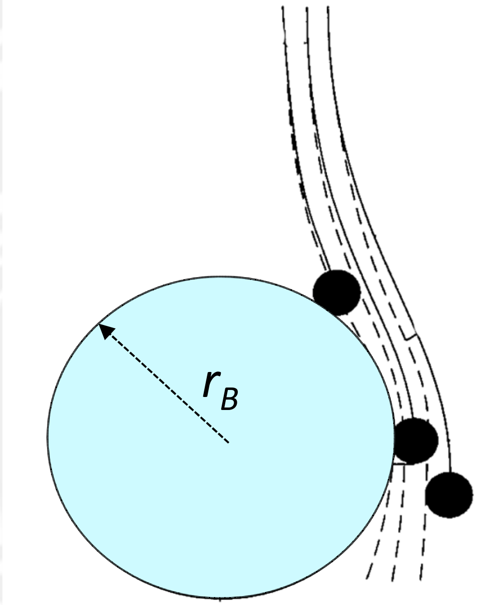
$$v_i^S = \frac{2}{9}\frac{g r_i^2}{\mu_L}\left(\rho_P - \rho_L\right)$$



$$n_{flott,i} = -v_i^S \cdot \frac{A_{slag}}{V_L} \cdot n_{iniz,i}$$

adhesion to Argon bubbles

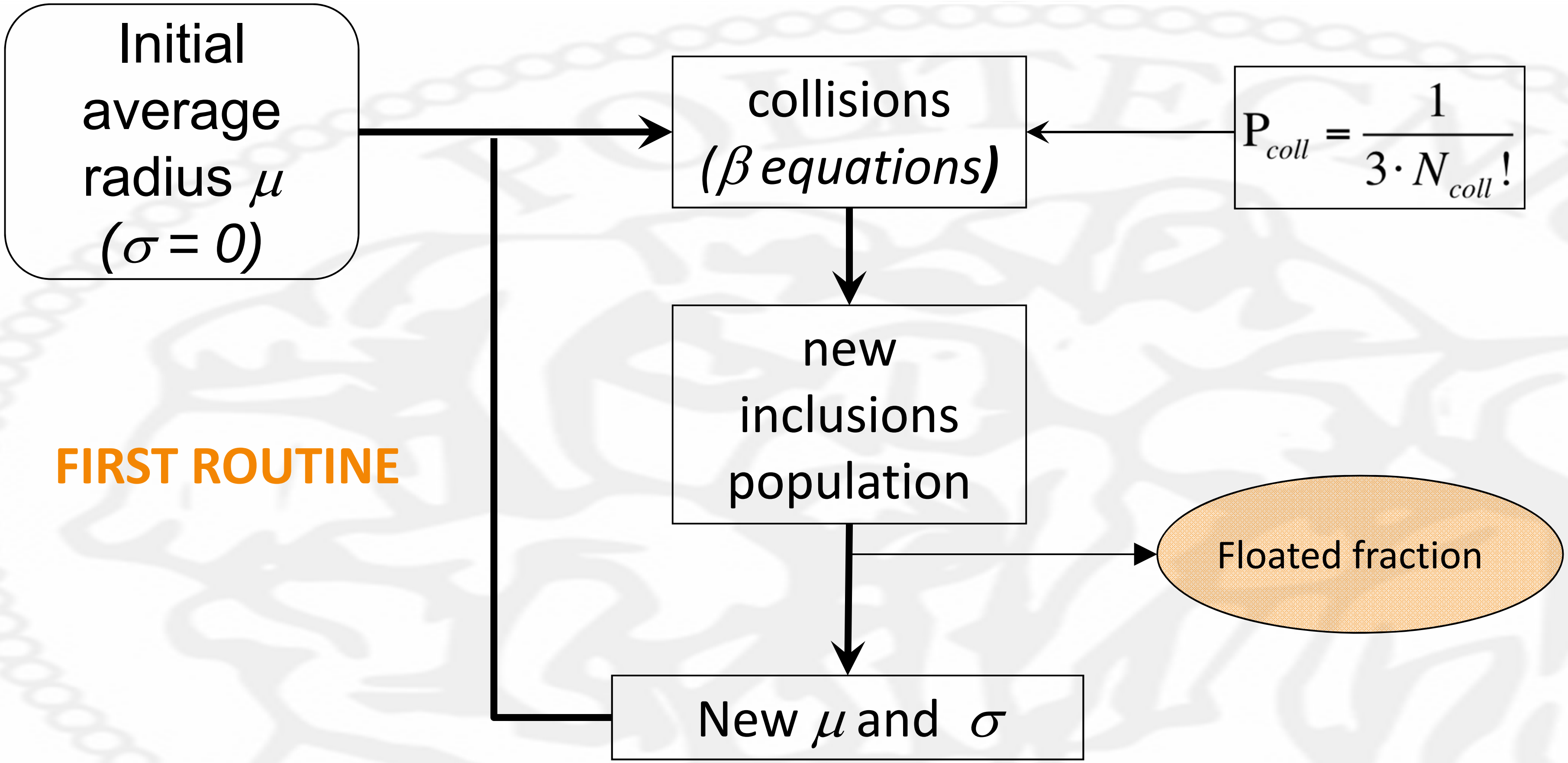
$$P = P_a \cdot P_c \cdot \left(1 - P_d\right)$$



$$n_{bolle,i} = -P \cdot N_b \cdot v_r \cdot \pi\left(r_b^2 + r_i^2\right) \cdot n_{iniz,i}$$

L.T. Wang et al., ISIJ Int., 2005, Vol. 45 No. 3, pp. 331–337

Model structure

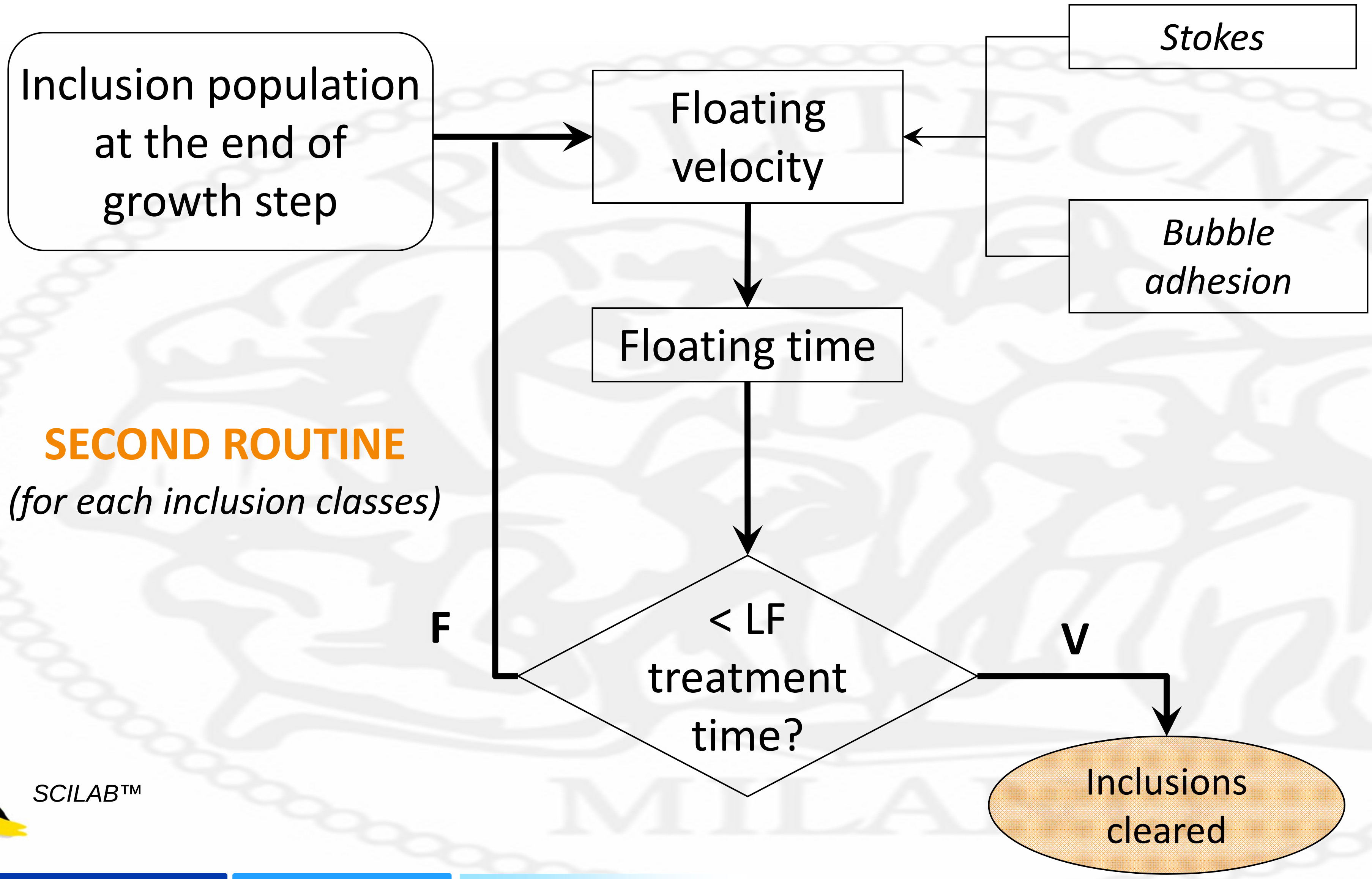


SCILAB™

Model structure

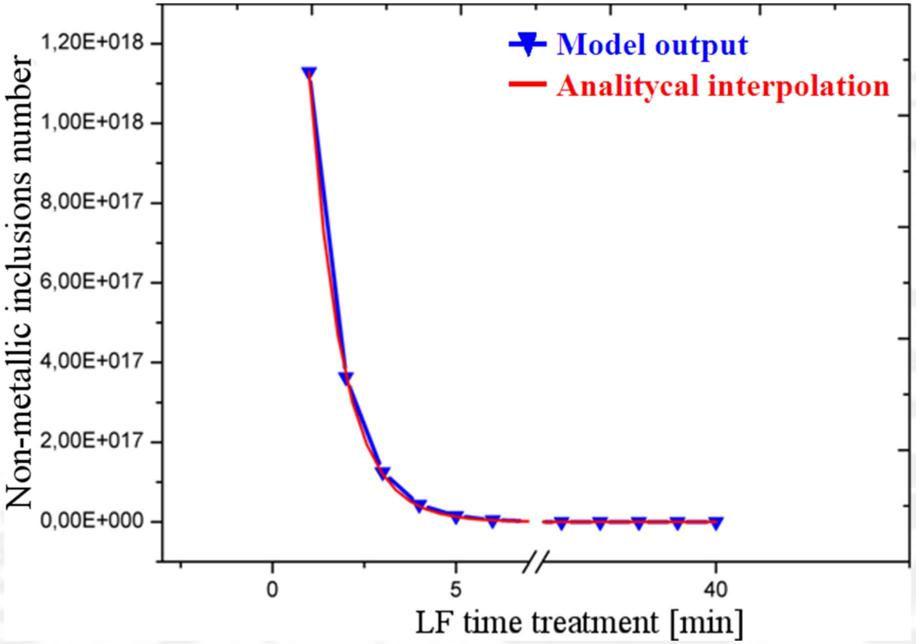
SECOND ROUTINE

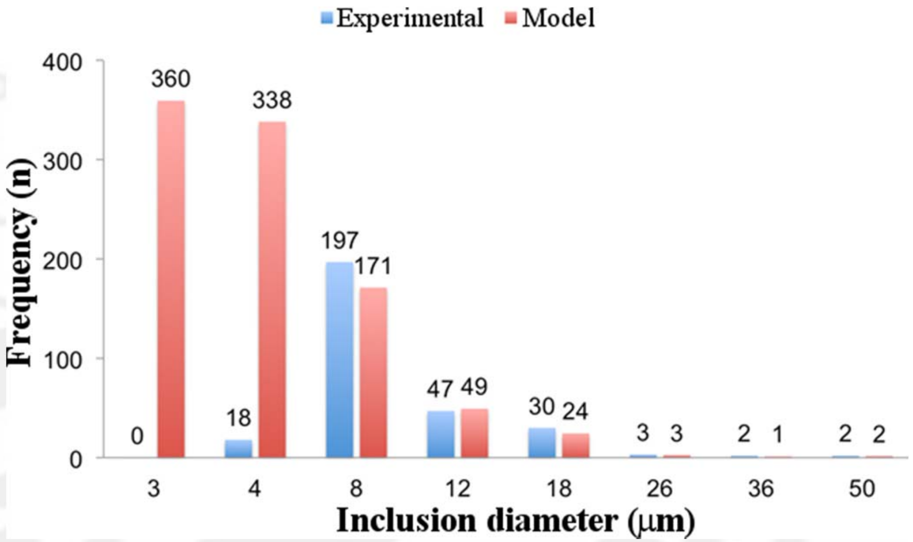
(for each inclusion classes)

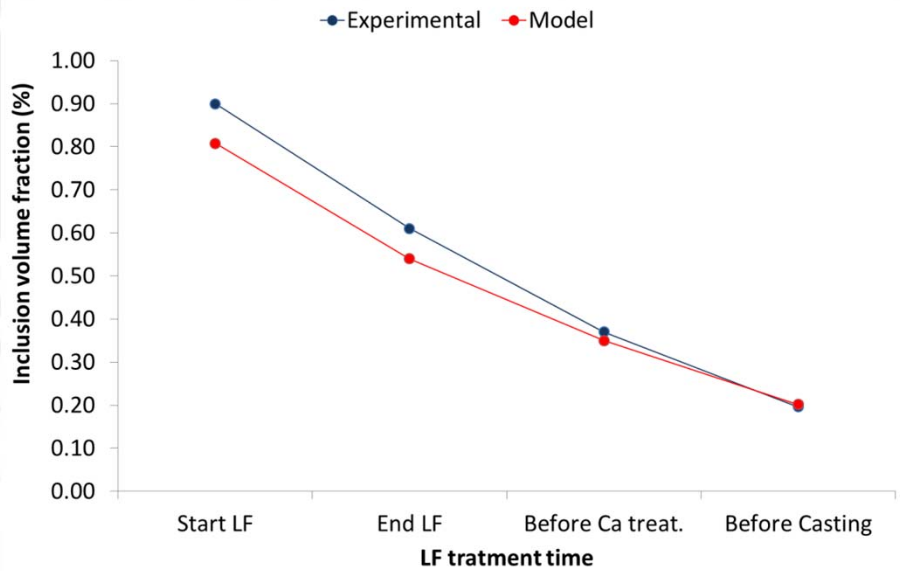


SCILAB™

Confronto modello - caratterizzazione







a. Same distribution between model and experiments

b. Good agreement between size and frequency

c. Good prediction of volume fraction through-out LF process

PREDICTION OF SLAG PHASES DISTRIBUTION THROUGH CHEMICAL COMPOSITION

Model principia

1. the minimization of the O_2^- free anions within the ionic solution

2. the hierarchy of the reaction has been stated on the basis of the optical basicity of the main species taken into account: CaO, SiO_2, Al_2O_3, MgO and (FeO+MnO)

3. the thermodynamic driving force depends on the optical basicity difference of the involved chemical species

   high optical basicity value = oxygen donor
   low optical basicity = oxygen acceptor

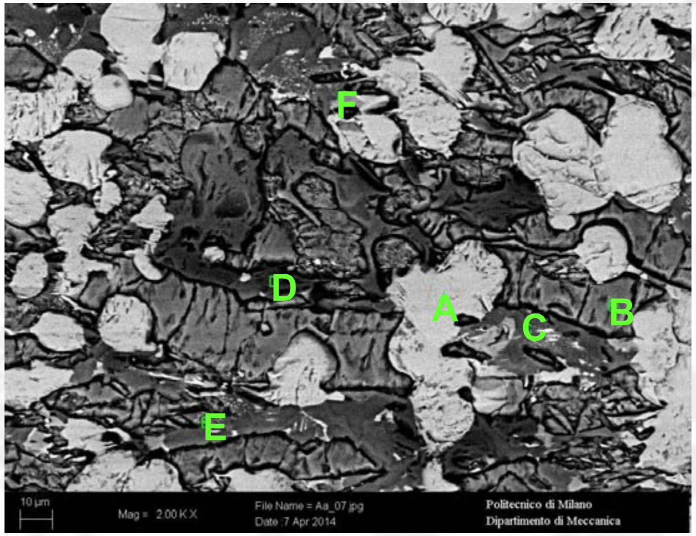
4. the system has been articulated in different thermodynamic cells

5. the chemical species have been distributed in the single cell as a function of the correspondent driving force

Example: EAF quality steel slag

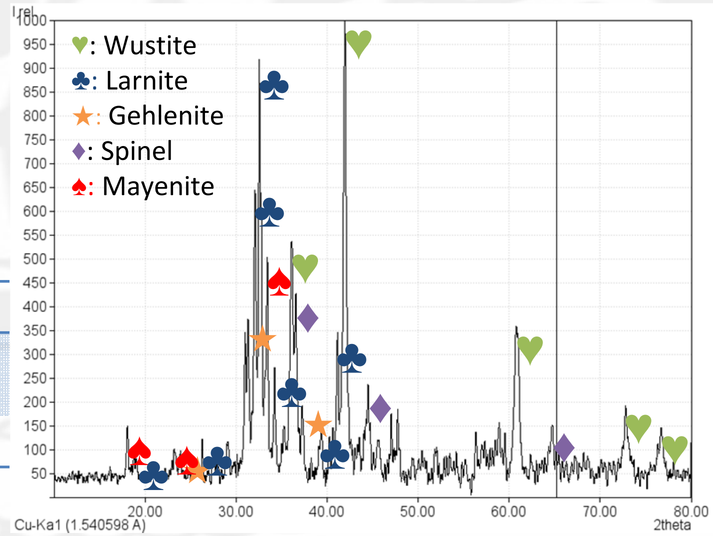
ED-XRF analysis [%wt.]

MgO	Al_2O_3	SiO_2	CaO	FeOx	MnO	Others
8.50	10.38	21.04	33.95	18.35	4.15	~ 3.00



SEM-EDS analysis [%wt.]

Point	Mg	Al	Si	Ca	Ti	V	Cr	Mn	Fe	Ba	ID
A	19.34	0.65		1.70		0.22	1.45	14.61	62.04		W
B			25.30	73.31		0.08				0.42	L
C		36.77	2.11	53.41		0.08		0.60	2.75	1.63	CA
D	15.82	53.31		0.85	0.66	0.37	6.43	5.70	16.47	0.39	Sp
E	1.42	30.31	9.35	44.08	1.08	0.24	0.04	2.02	10.84	0.62	G
F		7.01	2.61	45.49	30.94	1.33	0.9		6.19	2.30	Per



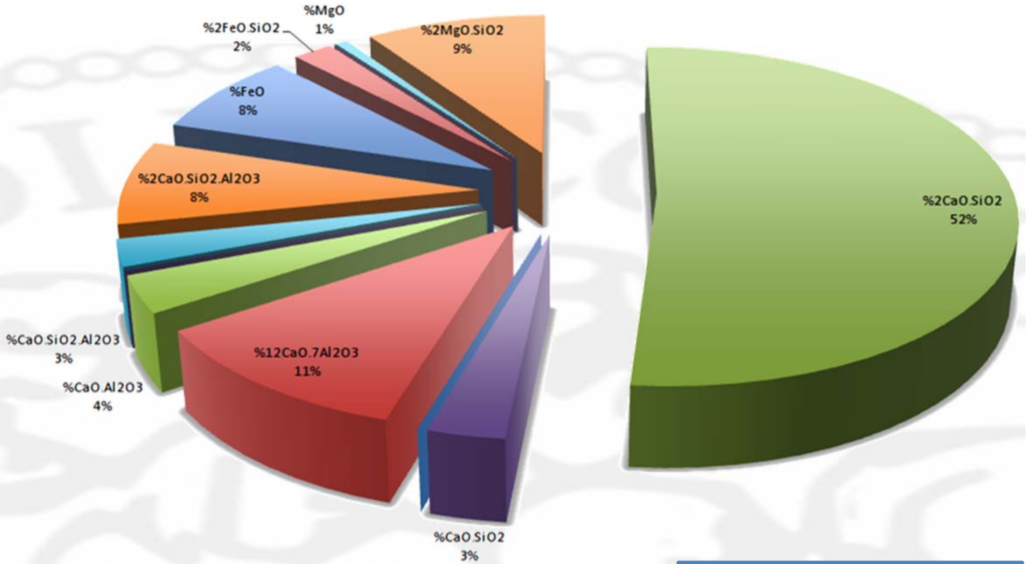
* Software internal limit

XRD analysis [%wt.]

Gehlenite $2CaO.Al_2O_3.SiO_2$	Larnite $2CaO.SiO_2$	Mayenite $12CaO.7Al_2O_3$	Spinel $(Mg,Al)(Al,Cr)_2O_4$	Wustite (Fe,Mg,Mn)O	U.S.*
15.5	54.5	9.1	3.4	11.6	5.8

Model prediction - %wt.

Phase	Experimental [wt%]	Model [wt%]	Delta %
Larnite (calcium silicate)	54.5%	55% (52% $2CaO.SiO_2$ +3%$CaO.SiO_2$)	+0.5%
Wustite	11.6	11% (8%FeO+1%MgO +2%$2FeO.SiO_2$)	-0.6%
Gehlenite	15.5%	11% (8%$2CaO.SiO_2.Al_2O_3$ +3%$CaO.SiO_2.Al_2O_3$)	-4.5%
Calcium aluminate	9.1%	15% (11%$12CaO.7Al_2O_3$ +4%$CaO.Al_2O_3$)	+6%



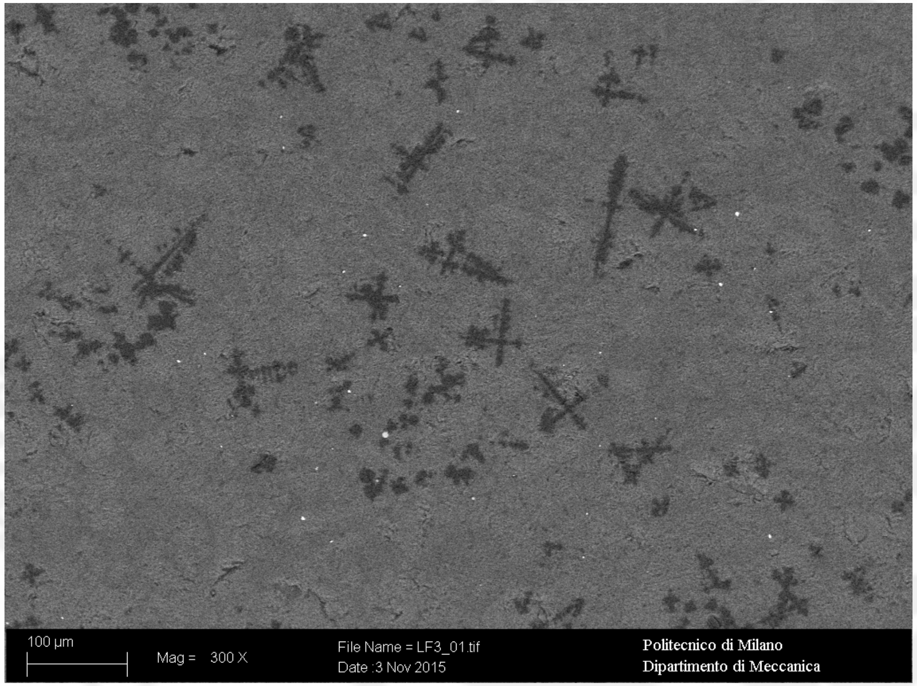
Weight fraction

The model is in good agreement with experimental analysis (error < 5%)

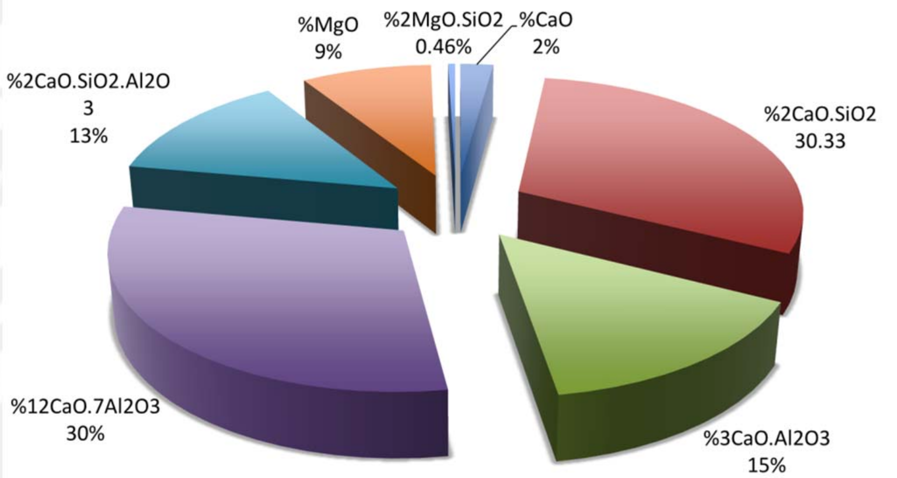
The model do not take into account the formation of Mg-Al-Cr spinel

Extension to LF slag

- The model can be adapted to predict composition of LF slag



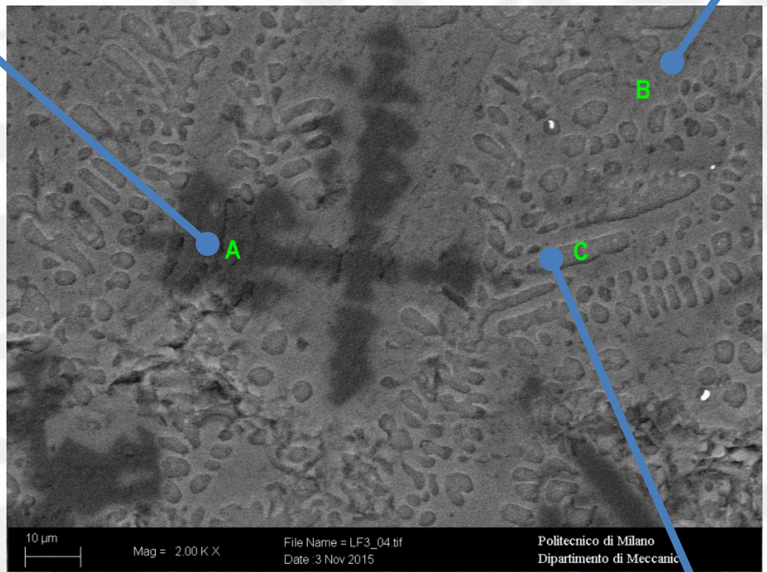
SEM-EDS [%wt.]				
[%wt.]	Mg	Al	Si	Ca
LF	8.3	22.8	10.0	58.9
	8.5	23.5	9.0	59.0



Phase	Calculated [wt%]	Model [wt%]	Delta %
Larnite (calcium silicate)	28.7%	30% (30% $2CaO.SiO_2$)	+1.3%
Periclase	8.5%	9% (9% MgO)	+0.5%
Calcium aluminate	62.8%	58% (30%$12CaO.7Al_2O_3$ +15%$CaO.Al_2O_3$ +$13CaO.Al_2O_3.SiO_2$)	+4.8%

Extension to LF slag

	Mg	Al	Si	Ca	Fe
%wt,	98.7			1.3	
%at,	99.2			0.8	
MgO					



	Mg	Al	Si	Ca	Fe
%wt,	6.7	31.7	5.0	56.7	
%at,	9.0	38.6	5.8	46.5	
$3CaO.Al_2O_3$					

	Mg	Al	Si	Ca	Fe
%wt,	0.7	6.2	22.3	70.8	
%at,	1.1	8.2	28.1	62.6	
$2CaO.SiO_2$					

Contatti

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