Korean Institute of Metals and Materials

Requirements on Internal Quality of Bloom Products

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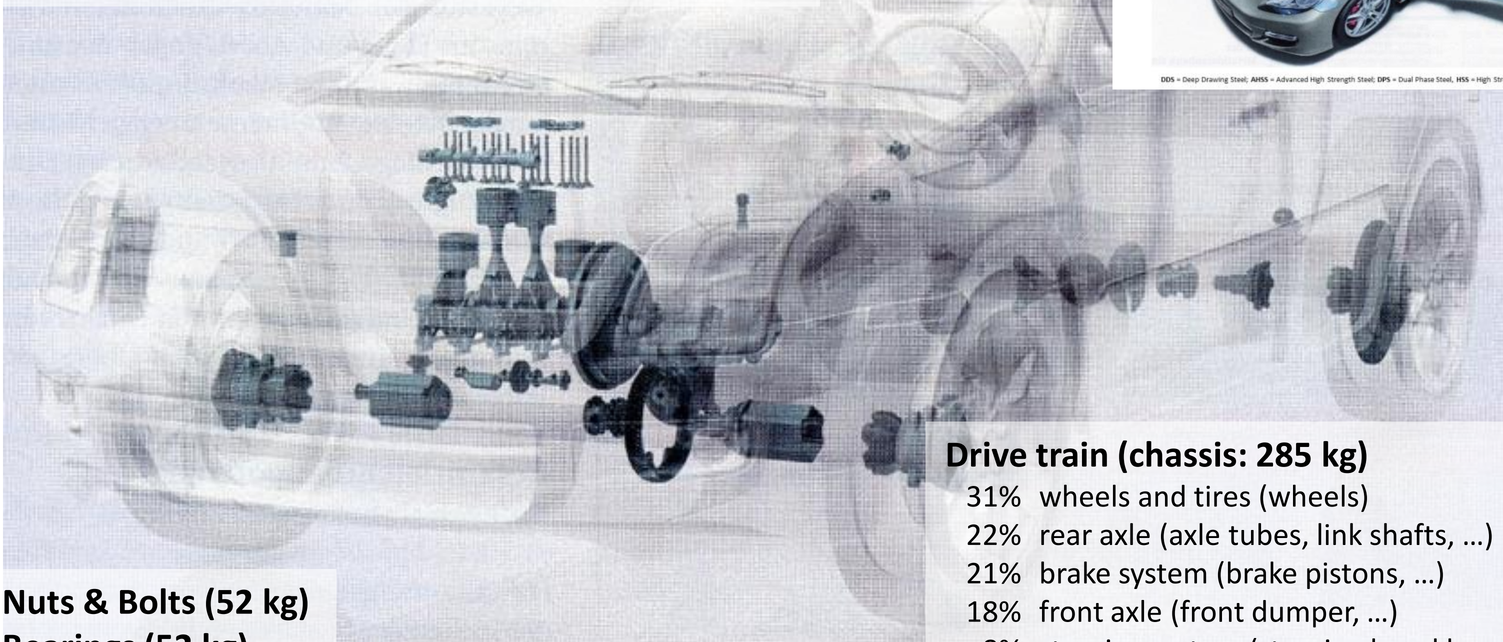
Metallurgical Symposium
October 27th, Busan, Korea

Agenda

1. Introduction
2. Trends in Automotive Markets and Impact on Steel Product Requirements
3. Defects on Bars and Wires and their Origin (Internal Defects)
4. Testing Methods and Quality Rating (Cracks, Macro & Micro Cleanliness, Segregations)
5. Bloom Casting Process (CCM Layout, Quality Results)
6. Metallurgical Process Route (Process Routes, Quality Results)
7. Conclusion/Outlook

Steel Products in Car Engine and Drive Train Manufacturing (Long Products)



Power train (transmission/gear: 400 kg)

59% engine (crankshaft, fuel pump, cylinders, ….)
16% troques converter (differential case, yoke, ringgear, ...)
16% transmission (gear, manual transmission, …)
9% drive shafts (lay shafts, output flange, …)

Drive train (chassis: 285 kg)

31% wheels and tires (wheels)
22% rear axle (axle tubes, link shafts, …)
21% brake system (brake pistons, …)
18% front axle (front dumper, …)
8% steering system (steering knuckle, …)

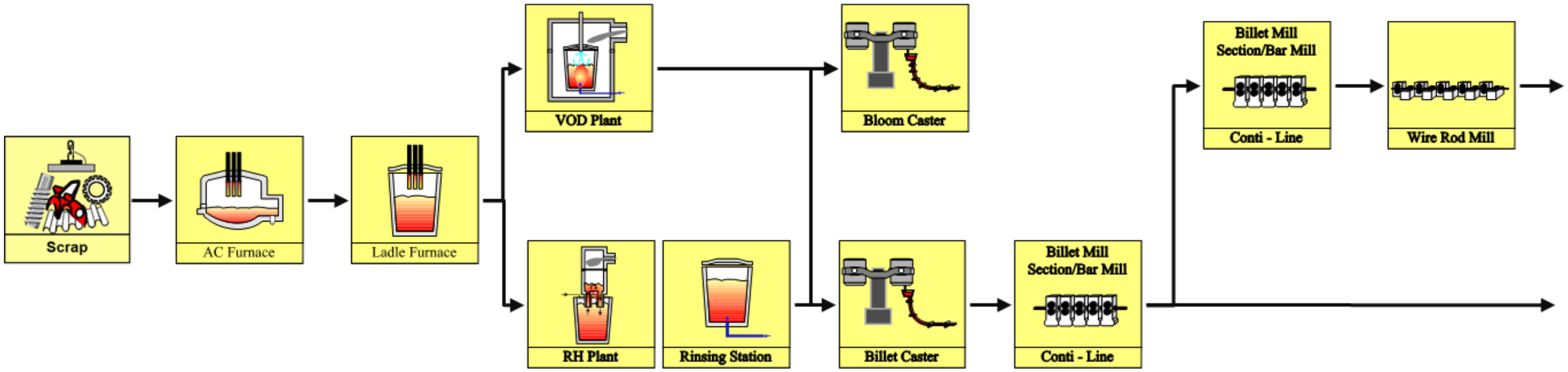
Nuts & Bolts (52 kg)
Bearings (52 kg)

Total weight balance:
1.740 kg/car = 39% body + 23% power train + 16% drive train + 16% interior + 6% electronics (share of steel = Ø 57,6 % (53-61%))

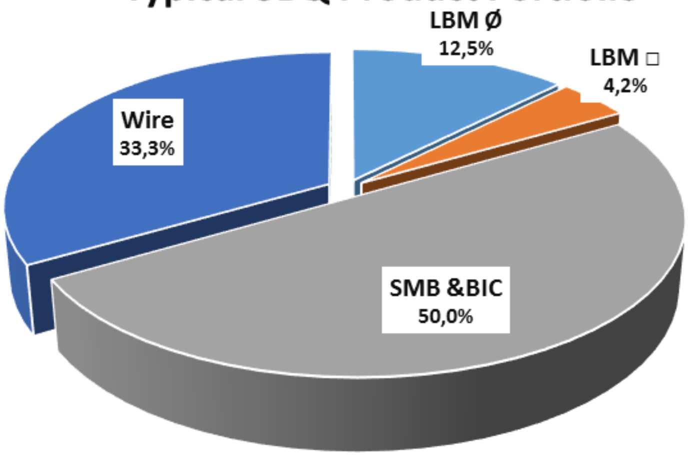
Source: Initiative Massiver Leichtbau

Introduction

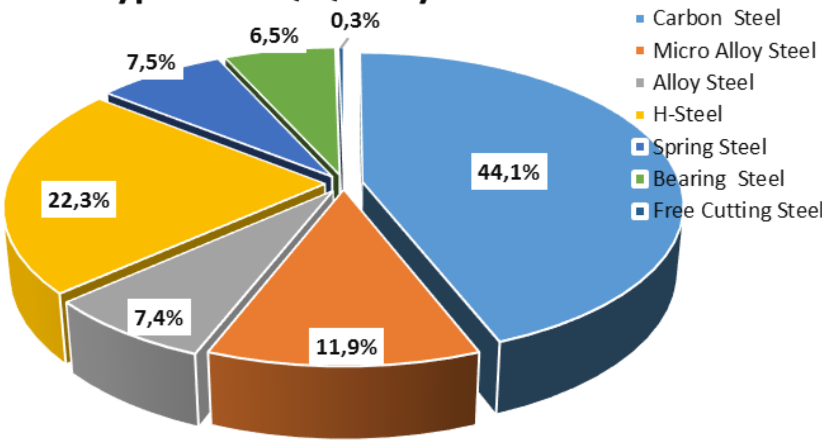
Typical Special Bar Quality (SBQ) Mill Layout



Typical SBQ Product Portfolio



Typical SBQ Quality Portfolio



LBM = heavy Section Mill SBM = light Section Mill
BIC = Bar in Coil Line Wire = Wire Rod Line

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Trends in Automotive Markets

General Trends

- Aim for individual, independent, motorized, any time available mobility
- Higher comfort standards (comfort, availability of space, variability, motoring comfort, quality of workmanship)
- Higher safety standards (passenger safety and pedestrian safety)
- Efficiency in cost of acquisition and running
- Warranties on complete vehicles and parts
- Environmental friendly technology

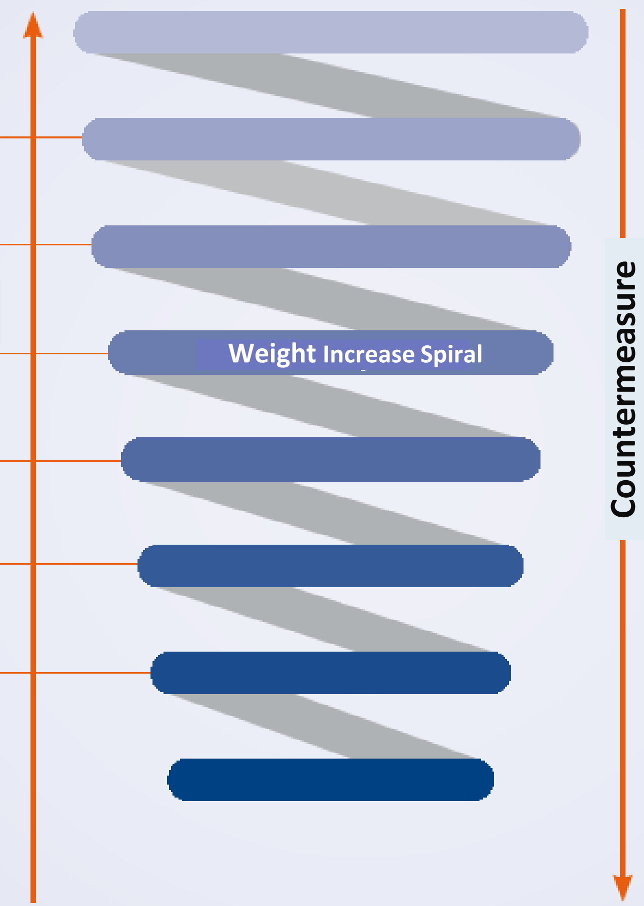
New Trends

- Electrification (desirable, ecofriendly products)
- Connectivity (extending lifestyle to the cars)
- Autonomous driving (fancy technology)
- Diverse mobility (consumers prefer access over ownership)

The “Spiral” of Weight Increase

Increasing Requirements

Safety	**+ kg**
Comfort	**+ kg**
Road Performance	**+ kg**
Space	**+ kg**
Variability	**+ kg**
Quality	**+ kg**



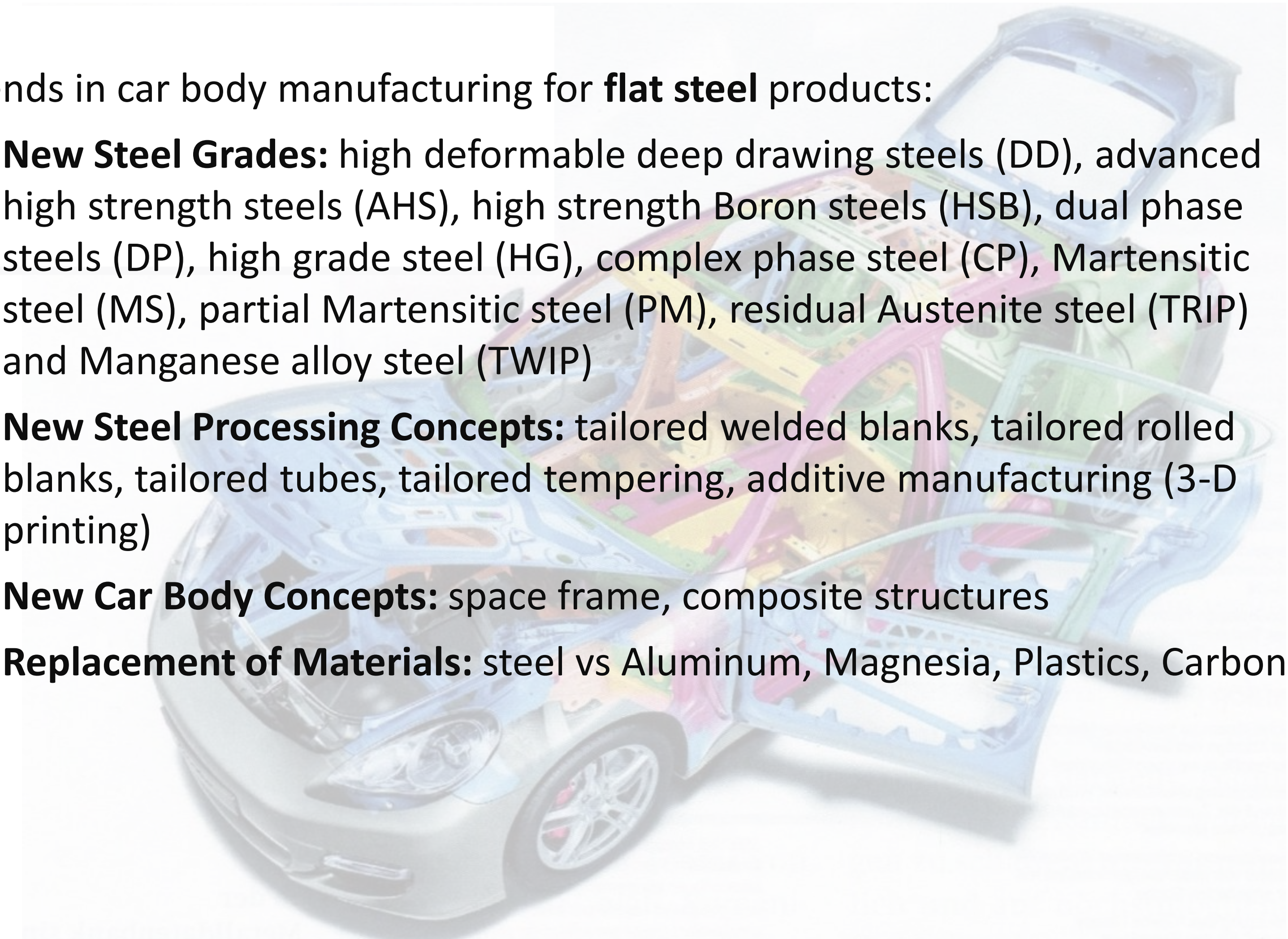
OEM’s:

- New Car Concepts
- Focus Car Body
- Top-Down Approach

Tear 1 & 2 Suppliers:

- New Materials
- New Processes
- Construction Know-How
- Design Know-How

Trends in Car Body Manufacturing (Flat Products)



Trends in car body manufacturing for **flat steel** products:

- **New Steel Grades:** high deformable deep drawing steels (DD), advanced high strength steels (AHS), high strength Boron steels (HSB), dual phase steels (DP), high grade steel (HG), complex phase steel (CP), Martensitic steel (MS), partial Martensitic steel (PM), residual Austenite steel (TRIP) and Manganese alloy steel (TWIP)
- **New Steel Processing Concepts:** tailored welded blanks, tailored rolled blanks, tailored tubes, tailored tempering, additive manufacturing (3-D printing)
- **New Car Body Concepts:** space frame, composite structures
- **Replacement of Materials:** steel vs Aluminum, Magnesia, Plastics, Carbon

Trends in Car Engine and Drive Train Manufacturing (Long Products)

Trends in automotive manufacturing for **long steel** products:

- **New/modified Steel Grades:** advanced high strength steels (AHS), high strength Boron steels (HSB), Bainitic steel (BDS), rear earth element steel (Tellurium), task is to reduce production cost by saving heat treatment
- **Design Optimization:** reduction of non stress bearing cross sections (tubes, hollows, webs, profiles), grooves, notches, dents, slim constructions, near-net shapes
- **New Steel Processing Concepts:** axial forming (tubes), swaging (hollows), forging of constrictions, combination of production processes, optimization of grain and surface treatment, additive manufacturing (3-D printing)
- **New Part Construction Concepts:** replacement of welded by forged constructions, replacement of screw by toothed connections, functional integration of parts, assembled vs massive parts
- **Substitution:** cast and welded steel vs forged Aluminum

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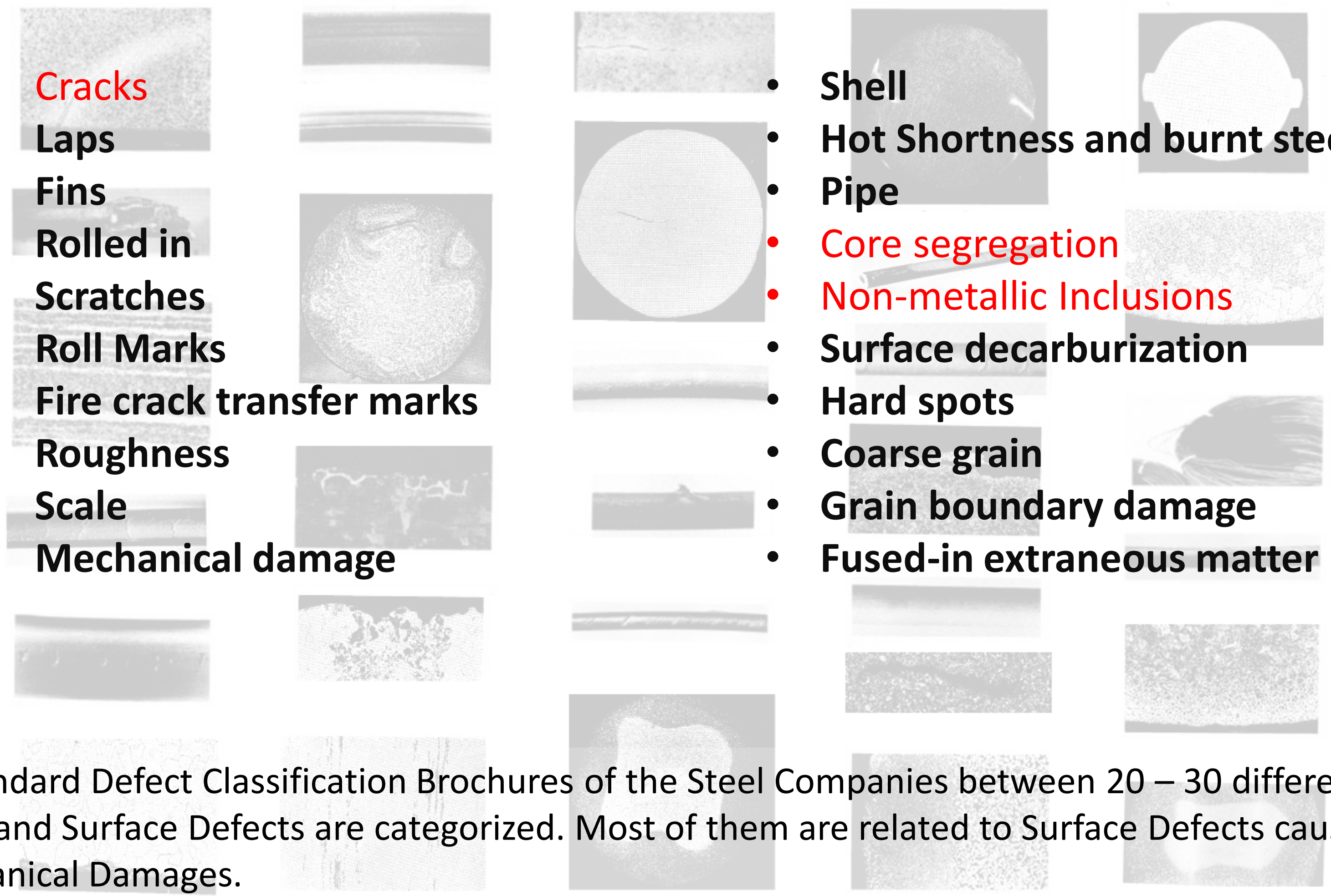
Categorized Defects on Bars and Wires



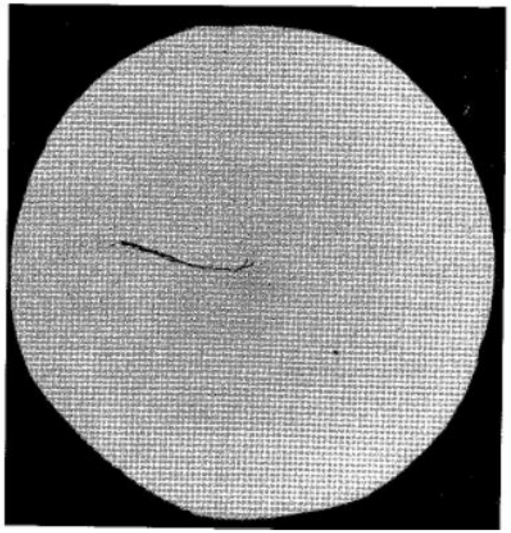
- Cracks
- Laps
- Fins
- Rolled in
- Scratches
- Roll Marks
- Fire crack transfer marks
- Roughness
- Scale
- Mechanical damage

- Shell
- Hot Shortness and burnt steel
- Pipe
- Core segregation
- Non-metallic Inclusions
- Surface decarburization
- Hard spots
- Coarse grain
- Grain boundary damage
- Fused-in extraneous matter

In Standard Defect Classification Brochures of the Steel Companies between 20 – 30 different Inner and Surface Defects are categorized. Most of them are related to Surface Defects caused by mechanical Damages.

Typical Bar & Wire Defects Caused from Internal Quality of Blooms & Billets

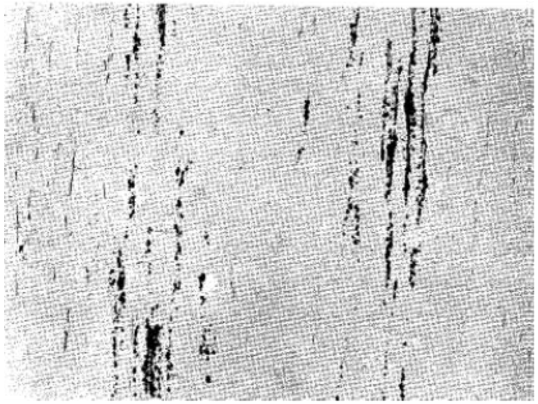
heavy pipe



occurrence
Cavity from casting, mostly connected with non-metallic inclusions.

detection
by ultrasonic testing billets or metallographic examination.

non-metallic inclusions

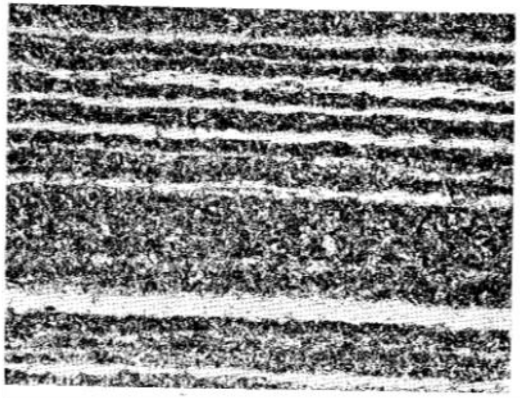


occurrence
by erosion of refractory linings, converters, ladles, runner bricks, during casting by casting powder in the mold (billet surface).

detection
by microscopic examination, blue brittleness specimens

core segregation

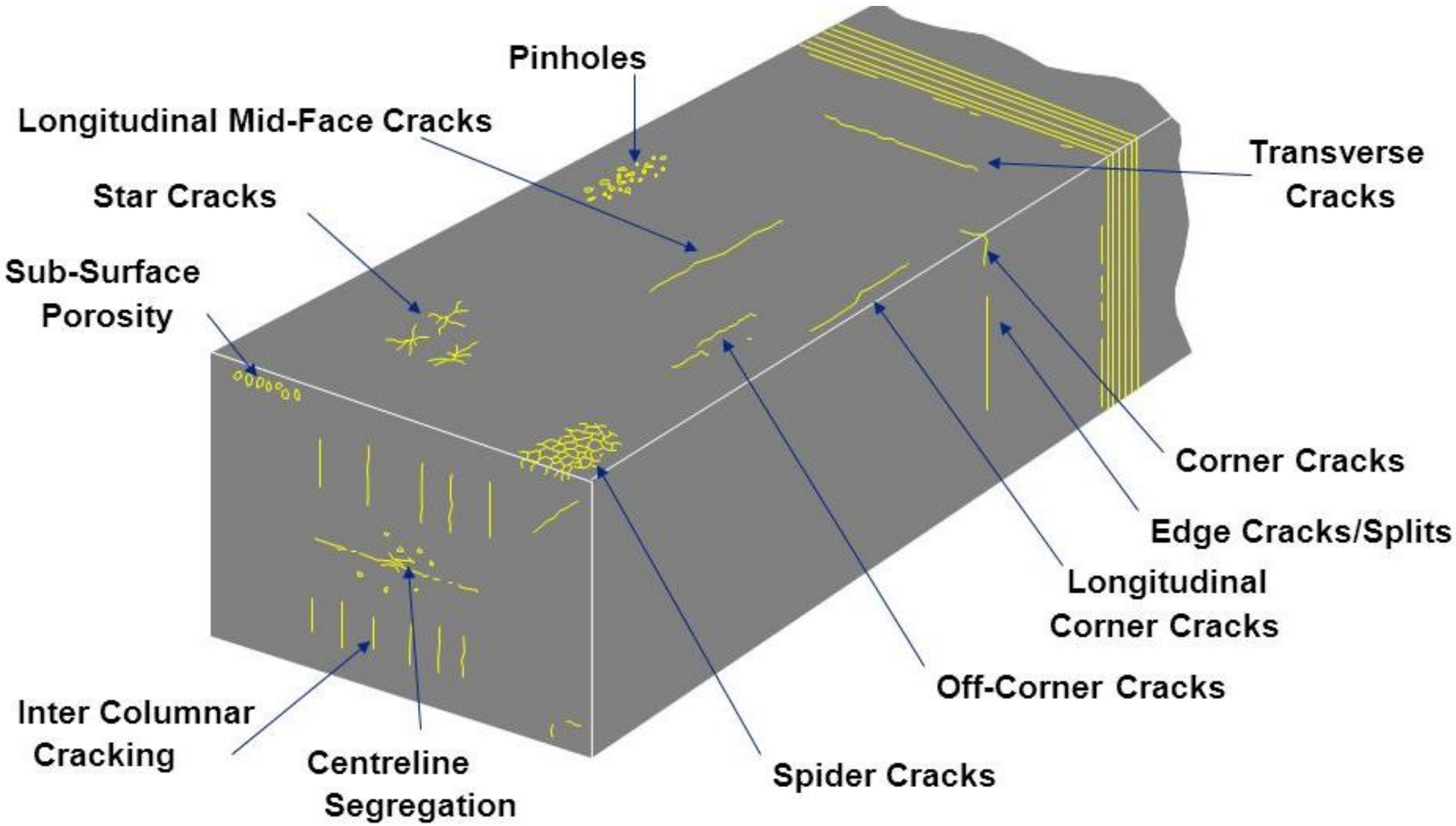
Phosphorus stringers



occurrence
cause of phase separation during solidification, mostly P, S and C are suspect able elements, not completely to avoid, very pronounced segregations are defects, to minimize by electric stirring in mold.

detection
by microscopic examination

Defect on Continuous Cast Materials



+ Scale, Oscillation Marks and Nonmetallic Inclusions

Source: Corus

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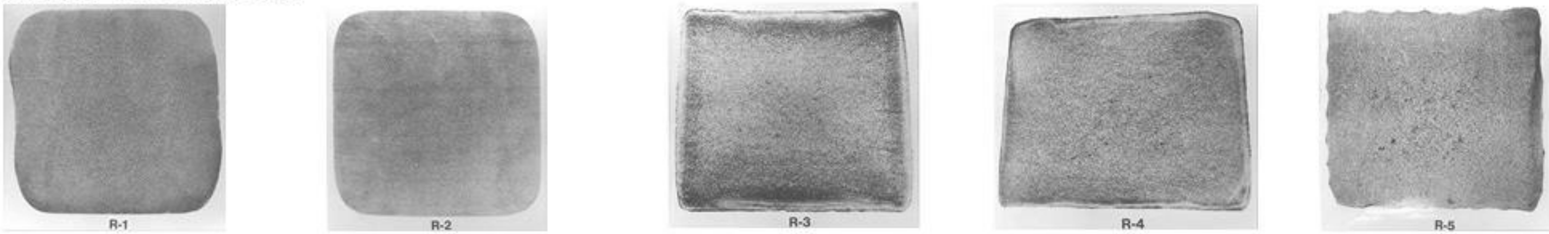
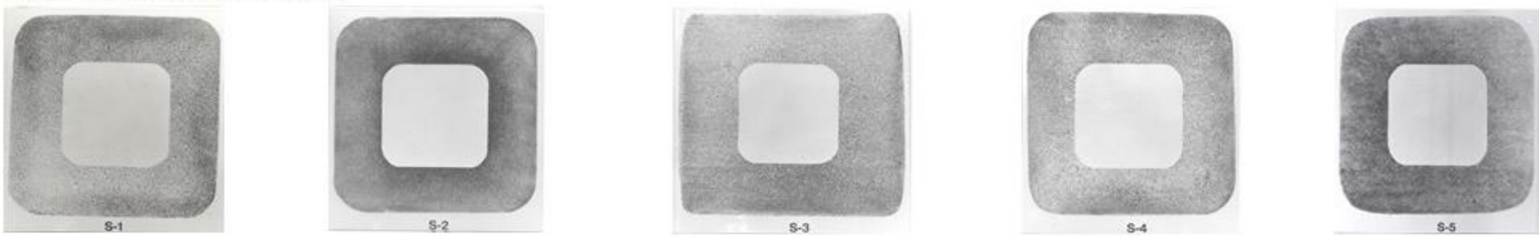
ASTM E381 (1993), the Basis for Steel Casting Quality Examinations

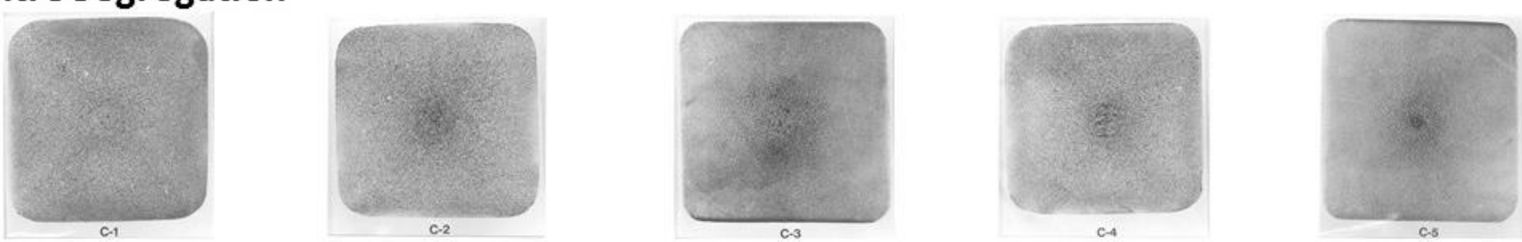
Random Conditions



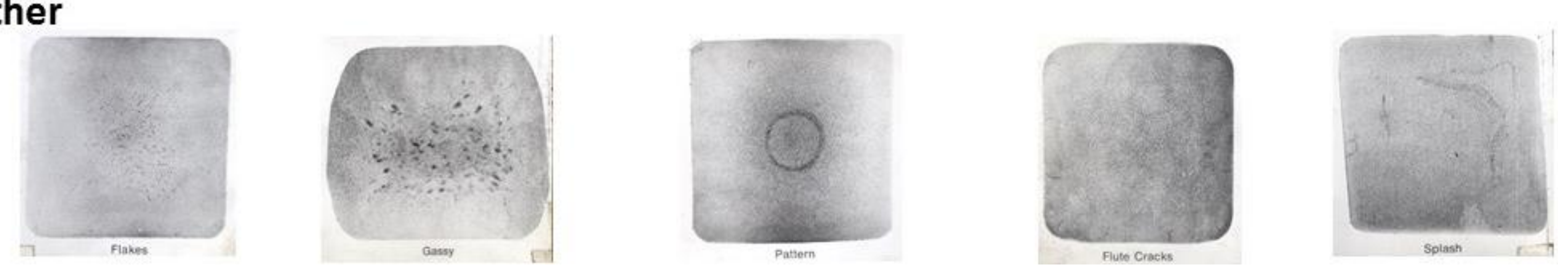
Subsurface Conditions



Centre Segregation

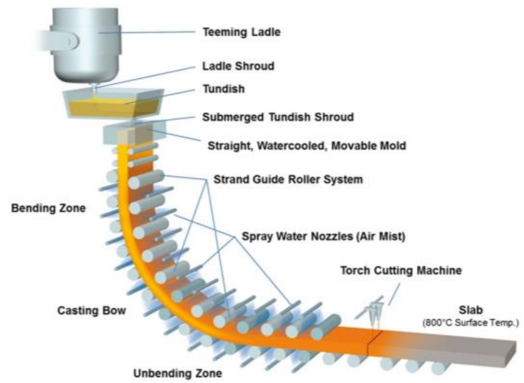


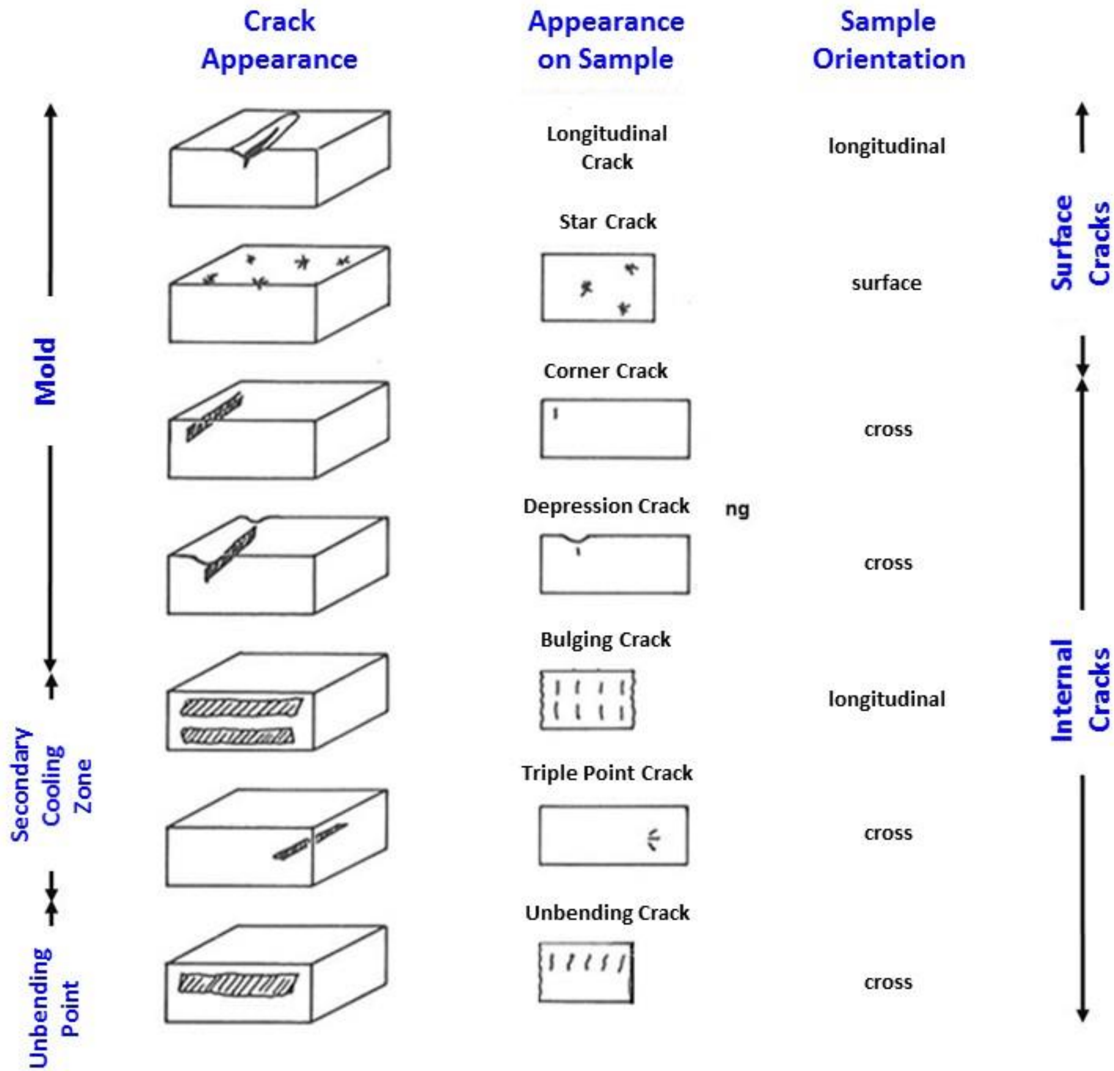
Other



Source : ASTM E381

Tensions & Hot Crack Forming during Bending & Unbending (1 of 3)

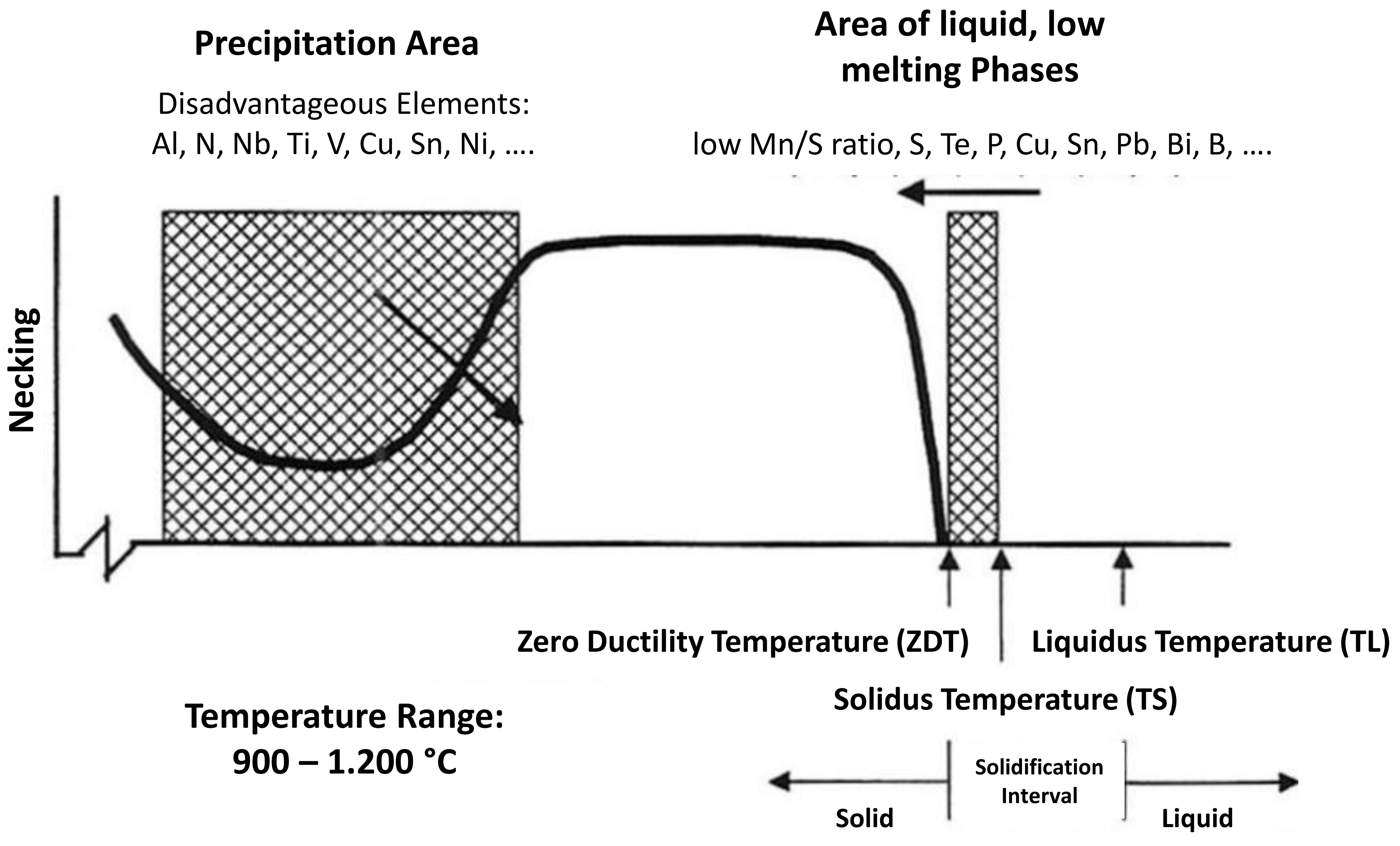




Source : Schrewe, H. ; Continuous Casting of Steel

Hot Crack Forming Fundamentals (2 of 3)

High-Temperature Ductility of Structural Steels, Areas of Reduced Ductility/Increased Hot Cracking Sensitivity



Source: Huchtemann, Wulfmeier; Stahl und Eisen 118 (1998)

Hot Crack Forming in Cast Material (2 of 3)

Example for Control Image Classification: **Internal Cracks**

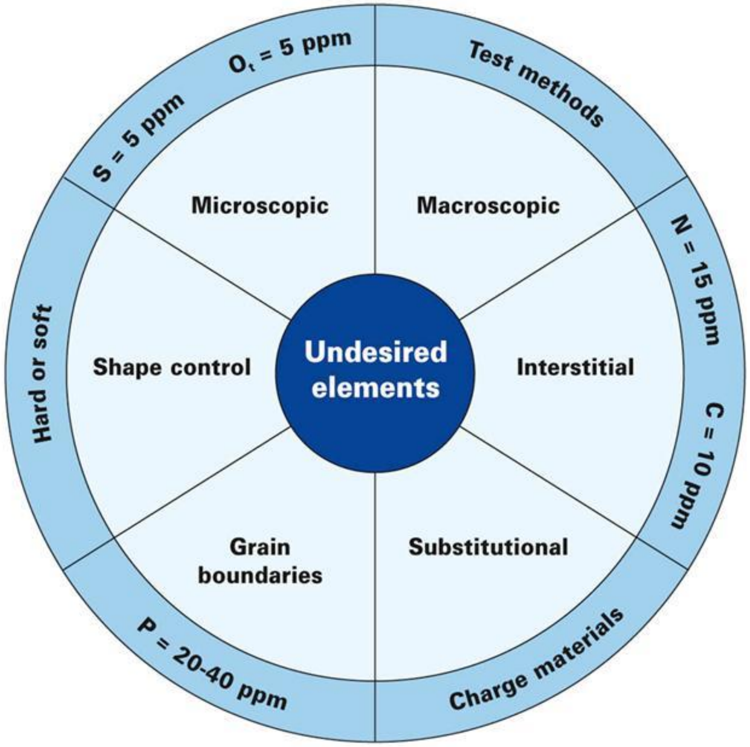
Class 1 | Class 2 | Class 3 | Class 4 | Class 5

Example for Control Image Classification: **Center Line**

Class 1 | Class 2 | Class 3 | Class 4 | Class 5

Various Classification Standards have been developed by the Steel Producing Companies available for Reference. The Quality Checks are carried out on Macro Etching Samples

Steel Cleanliness – Inclusions (1 of 12)



- Steel cleanliness is differentiated between **Microscopic** and **Macroscopic** inclusions.
- **Microscopic** inclusions in accordance with DIN 50602 are inclusions with a maximum size of 0,030 mm². The test is carried out by a microscope at x 100 magnification. So under a microscopic the maximum size of the inclusions are 100 mm x 3 mm.
- **Macroscopic** inclusions are inclusions exceeding the limit of microscopic inclusions

Standards for Determining Steel Cleanliness (2 of 12)

1) Microscopic Inclusions:

- DIN 50602 / ASTM E45 / ISO 4967 / EN 10247
- EN 10247 is not being used by customers. In Germany the (officially invalid) DIN 50602 is used by customers as their internal standard. A new version of the DIN 50602 is now being processed by the German Steel Institut VDEh
- ASTM E45 and ISO 4967 are similar.
- Convertibility between the ASTM E45 and DIN 50602 not possible

Type of Inclusions	DIN 50602	ISO 4967 / ASTM E 45
Sulfide Type	Inclusion SS	Group A
Aluminate Type	Inclusion OA	Group B
Silicate Type	Inclusion OS	Group C
Globular Oxide Type	Inclusion OA	Group D

Furthermore the ISO 4967 and ASTM E45 differentiate between inclusions of the **fine/thin** or **thick/heavy** series . The difference is in the width of the inclusion

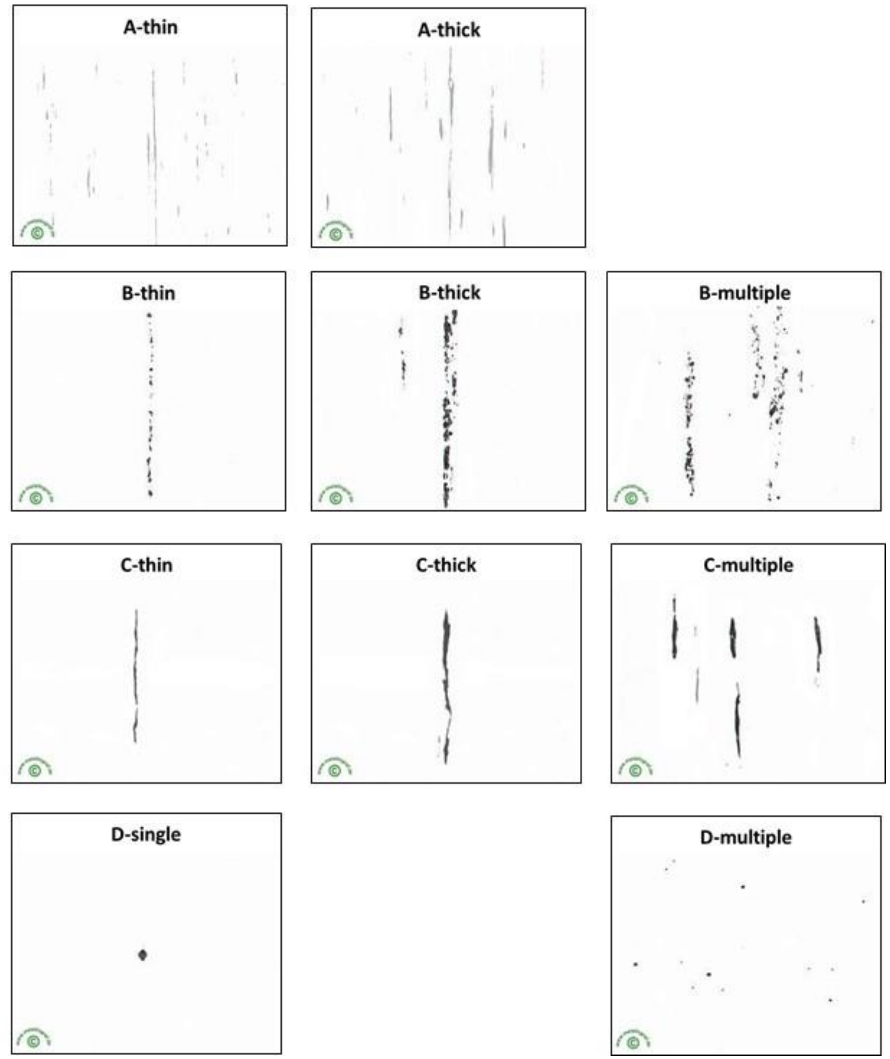
Micro-Inclusion Classification according to DIN 50602 (3 of 12)

A-Type Inclusions (Sulfide type, MnS), higly malleable, individual grey particles with a wide range of aspect ratios (length/ width) and generally rounded ends, deformable during rolling

B-Type Inclusions (Alumina type,Al_2O_3), numerous non deformable, angular, low aspect ratio (generally <3), black or blueish particles (at least three) aligned in the deformation direction, cubic, stretchable during rolling

C-Type Inclusions (Silicate type, $(CaO)_m(SiO_2)_n$), highly melleable, individual black or dark grey particles with a wide range of aspect ratios (genarally >3), black or blueish, randomly distributed particles, deformable during rolling

D-Type Inclusions (Globular or oxide type, $(CaO)m(Al_2O_3)_n$, CaS), non deformable during rolling, angular or circular, low aspect ratio (generally <3), black or blueish, randomly distributed particles



Source: DIN 50602

Comments on Micro-Inclusions in Steel (4 of 12)

Standards for Determining Steel Cleanliness (5 of 12)

2) Macroscopic Inclusions

a) Tests on Rolled Samples:

- Blue Fracture Test (SEP 1584/ ISO 3763)
- Ultrasonic Immersion Test at FBH 0,3 mm (SEP 1927). This test can only be done on samples
- Inline Ultrasonic Test at FBH 0,7 mm or 0,5 mm (for mass production)
- Experiments are being carried out to do tests at FBH 0,2 mm (experimental stage)

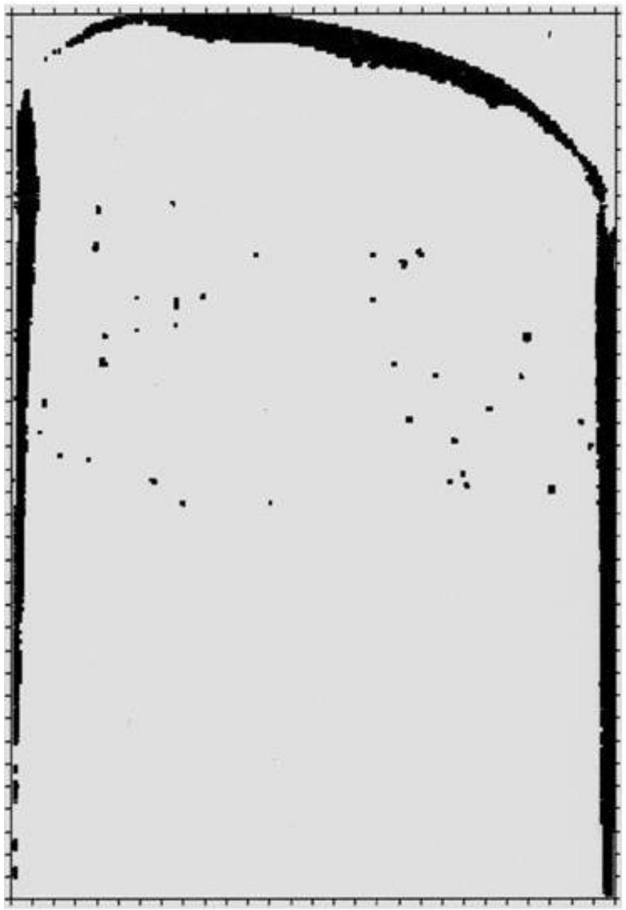
b) Test on CCM Samples:

- MIDAS (Mannesmann Inclusion Detection by Analyzing Surfboards) Testing Standard
- SILENOS Testing Standard

Abbreviations: SEP = Stahleisen Prüfblatt FBH =

Macro and Micro Inclusion Population on the same Specimen (6 of 12)

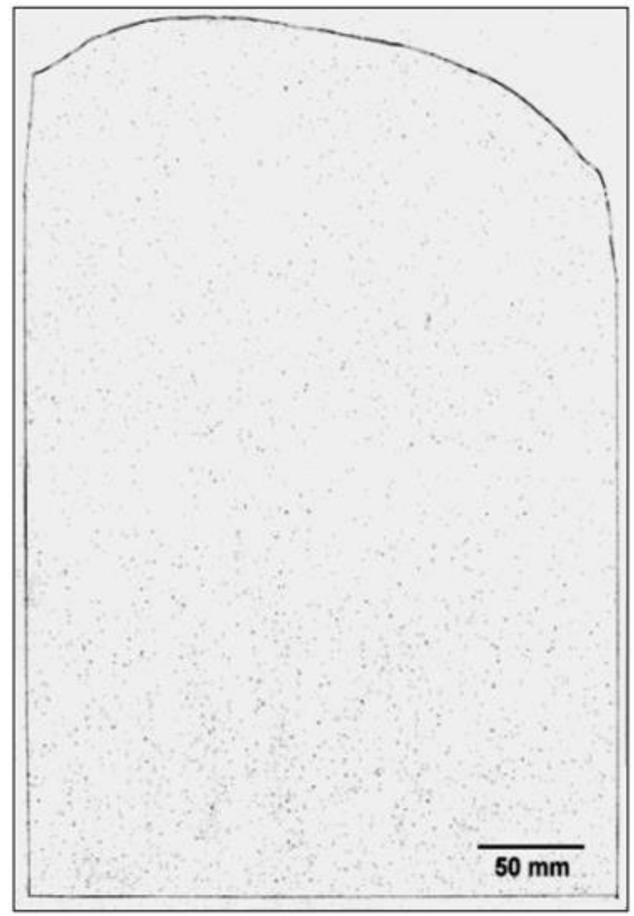
Macro-Inclusion Test Result
(MIDAS Standard)



Macro Inclusions (> 50 µm)

big (> 100µm) Ca_nAl_m inclusions without Sulfur in a narrow Inclusion band below the surface

Sulfur Print
(Baumann Standard)



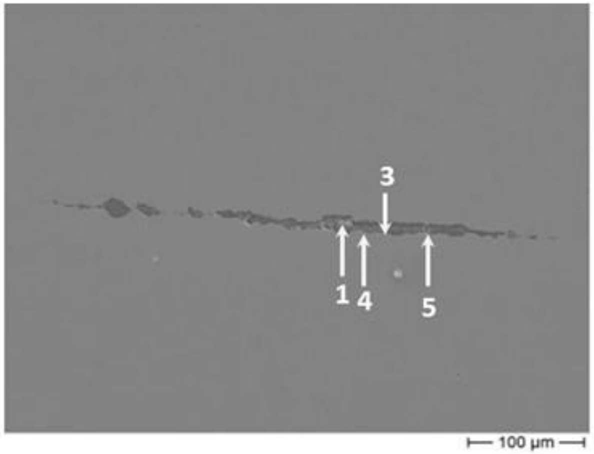
Micro Inclusions (< 30 µm)

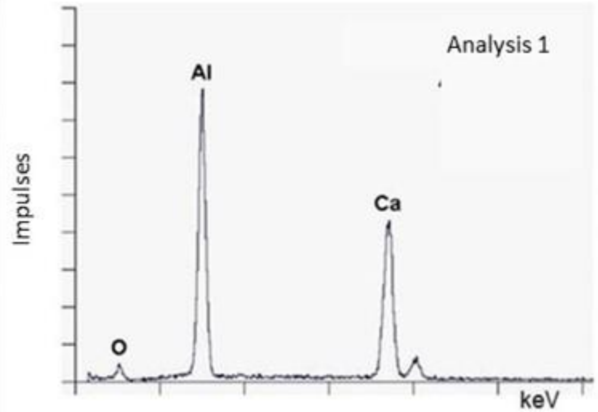
widely scattered, small (< 30µm) CaS inclusions

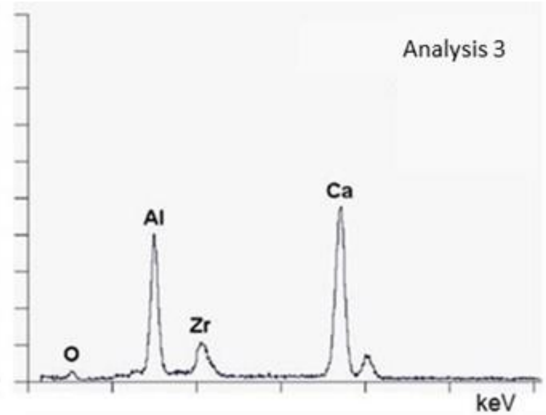
Source: SZMF

Macro and Micro Inclusion Population on the same Specimen (7 of 12)

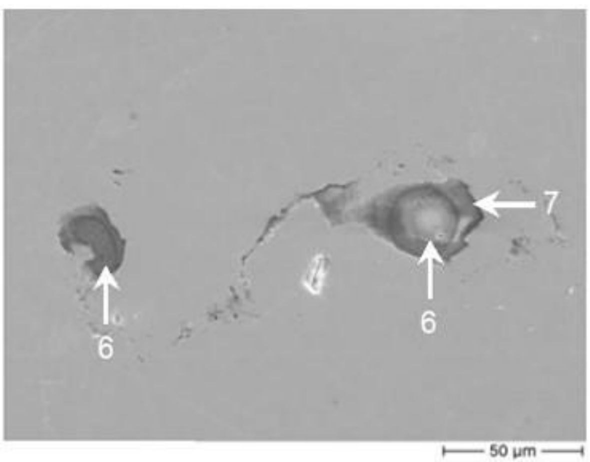
MIDAS Sample: Calcium-Aluminate Macro-Inclusions (> 50 µm) combined with SEN Refractory Particles (Zr)

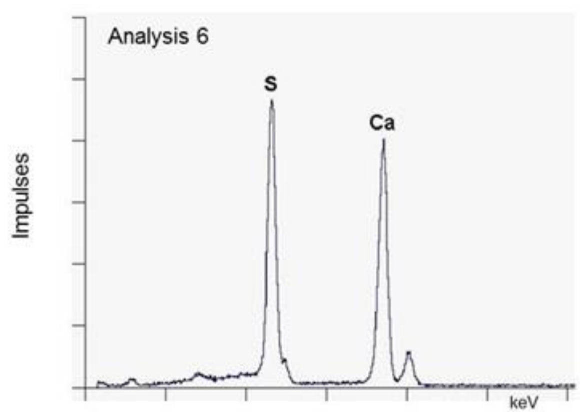


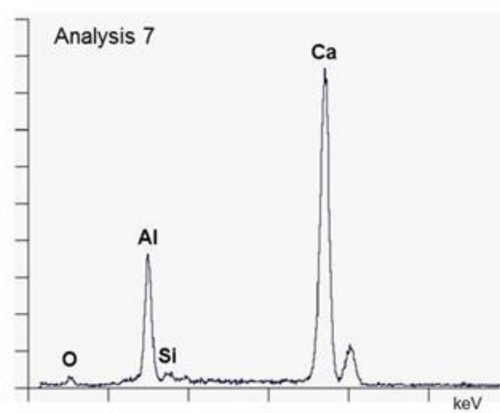




Sulfur Print Sample: Mixed CaS and Calcium-Aluminate Micro-Inclusions (< 30 µm)



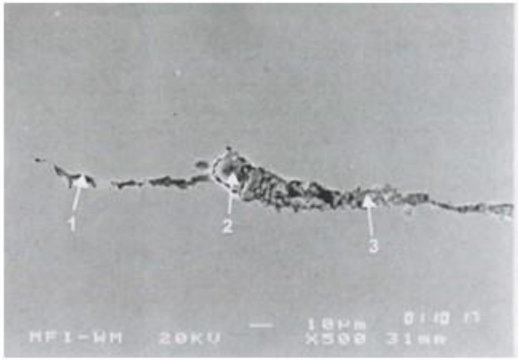


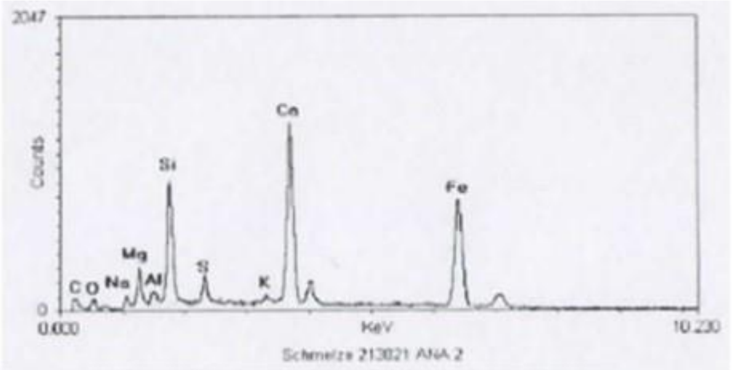


Source: HKM

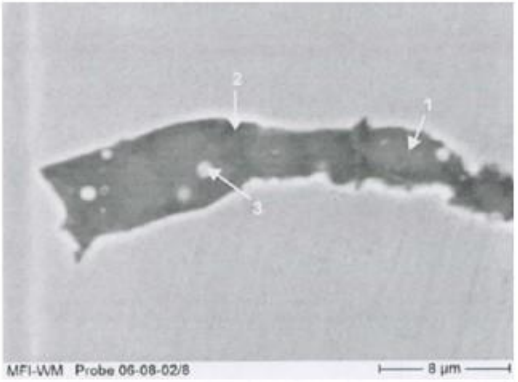
Macro Inclusion Types detected in (Si-killed) Steel (9 of 12)

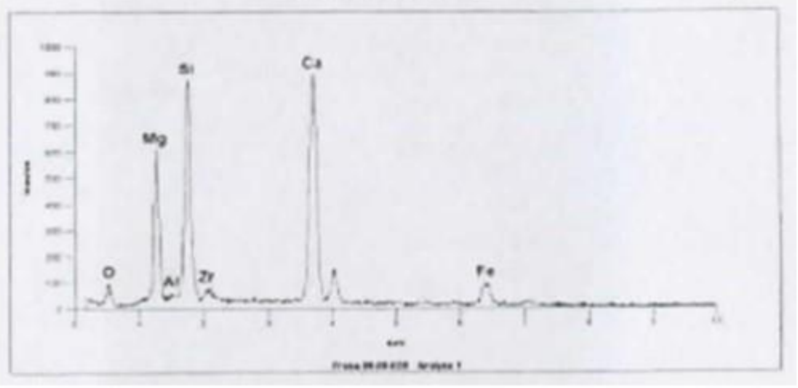
Multi-Phase Inclusion of **Casting Powder** (contaminated with Na, K)



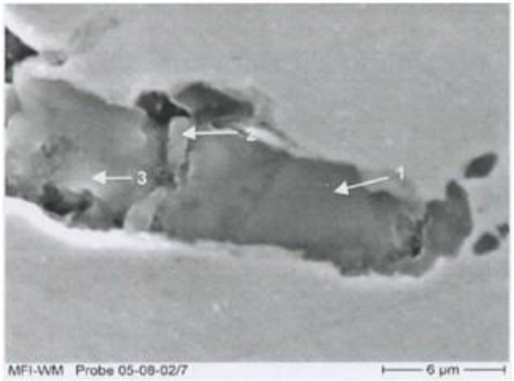


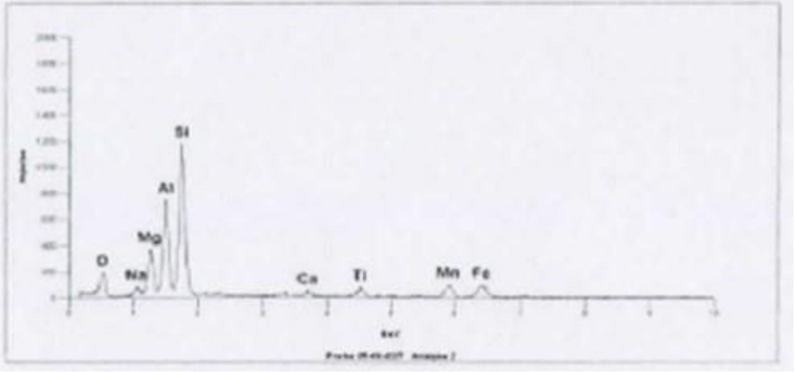
Multi-Phase Inclusion of **Ladle Slag** (contaminated with Zr)





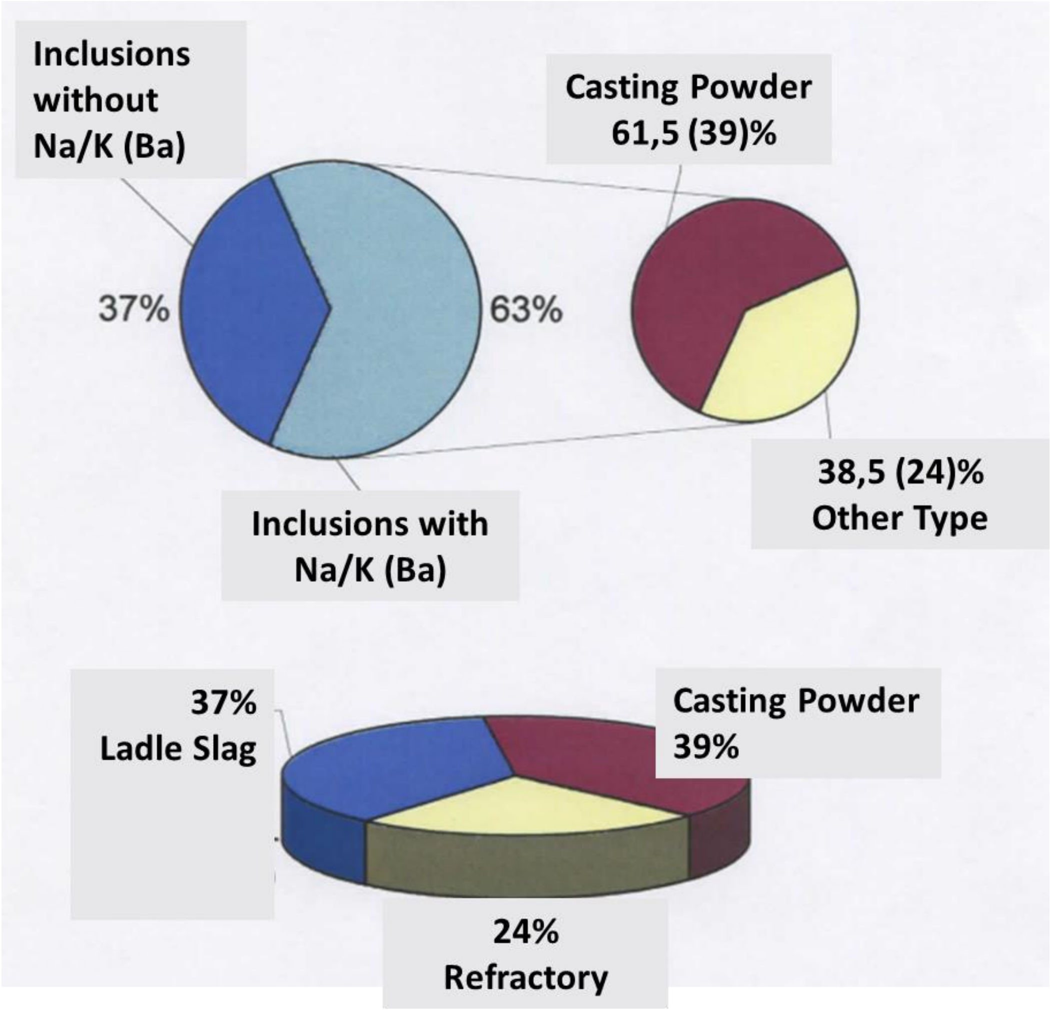
Multi-Phase Inclusion of **Refractory Material** (contaminated with Al, Si)





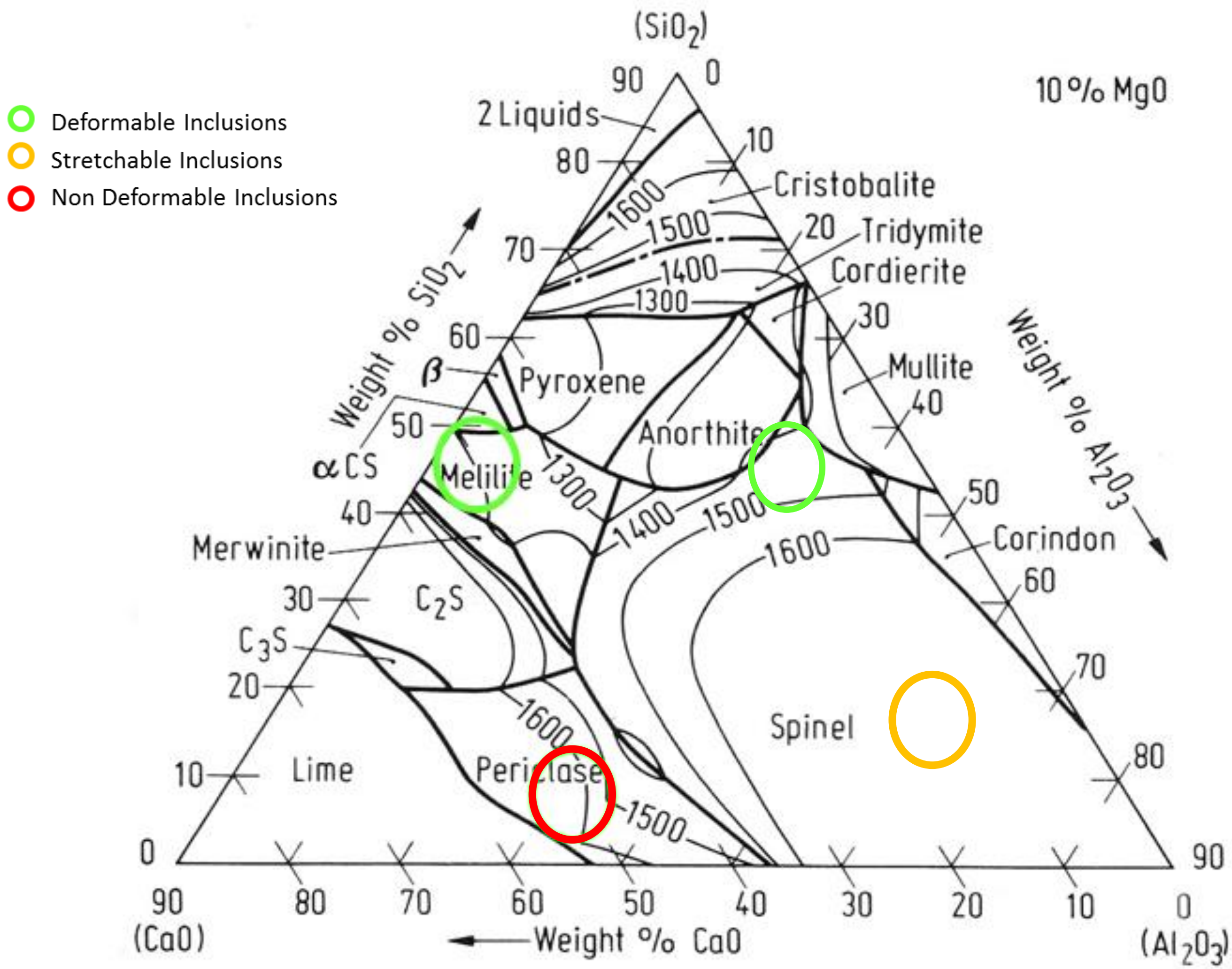
Source: SZMF

Origin of Macro Inclusion Types in (Si-killed Bearing) Steel (10 of 12)

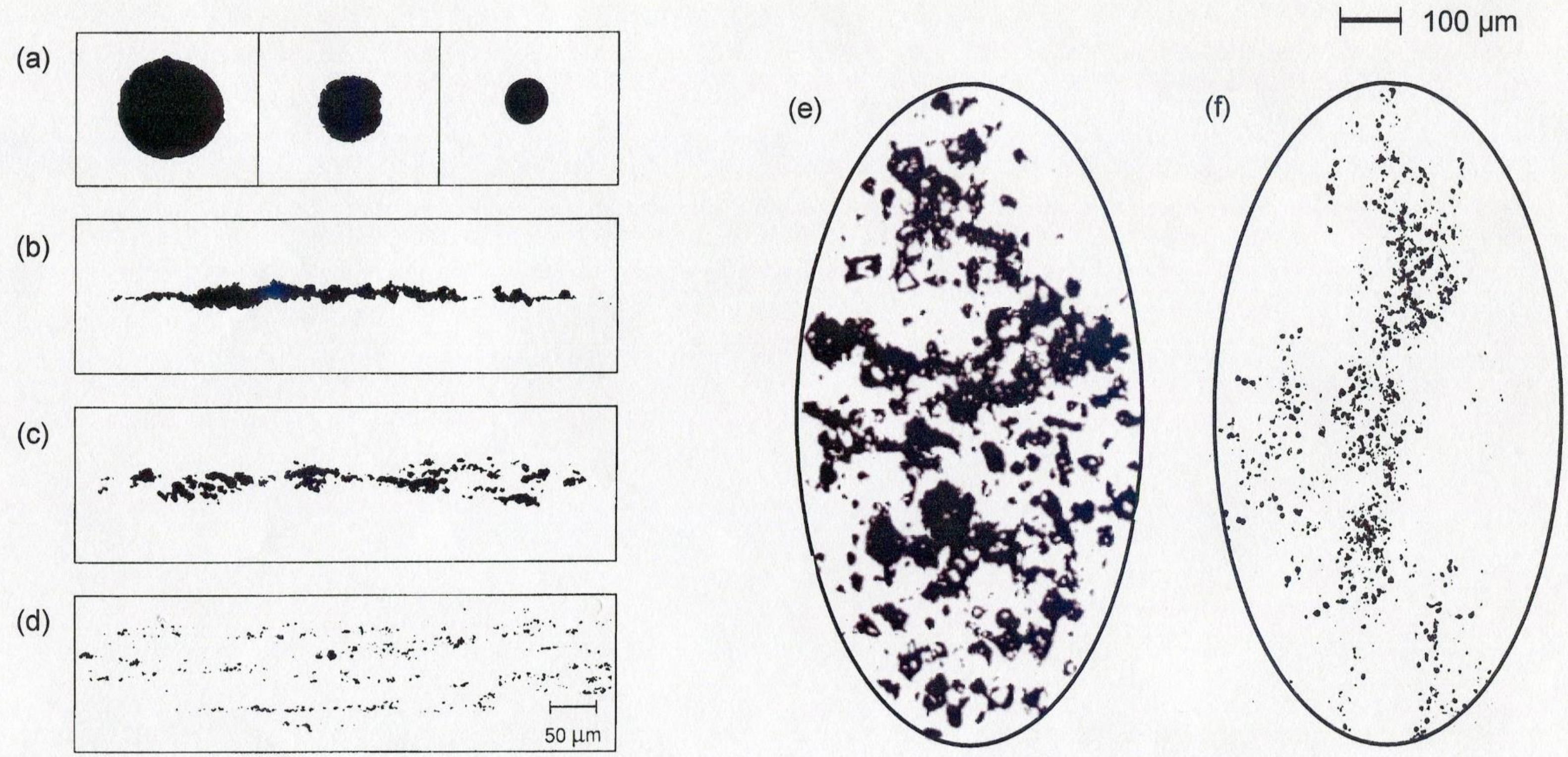


A long term investigation on inclusion types, detected by ultrasonic immersion testing on bearing steel came to the conclusion summarized above

Effect of Slag Composition on Inclusion Composition (11 of 12)



Deformability of Macro Oxide Inclusion Types (12 of 12)



Transverse micro-sections:

(a) Undeformable CA_2, CA_6 or Al_2O_3
(b,c) Plastic flow or disintegration of slag
(d) Dissemination of broken-off clusters

Horizontal micro-sections:

(e) Emulsified slag inclusion
(f) Coral-shaped alumina cluster

Source: SZMF

Hot Crack Forming in Cast Material (1 of 6)

Example for Control Image Classification: **Internal Cracks**

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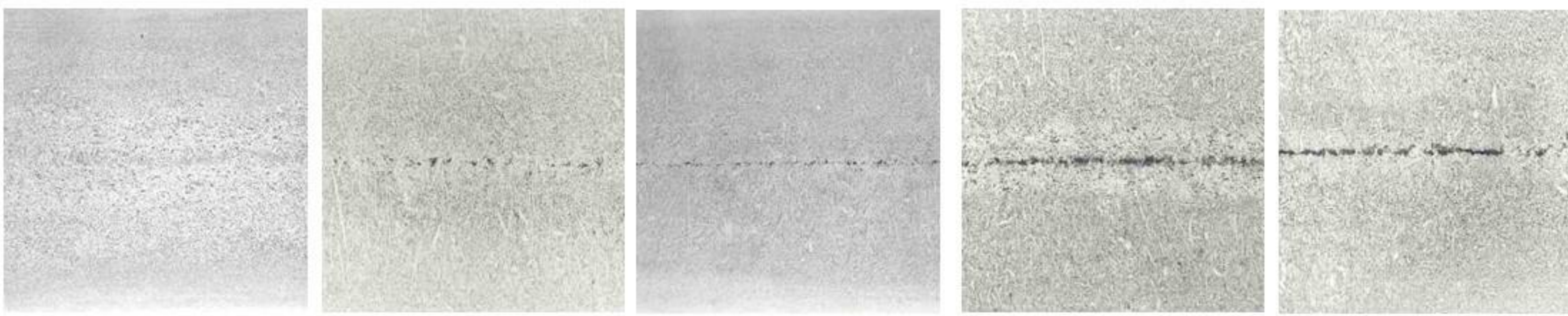
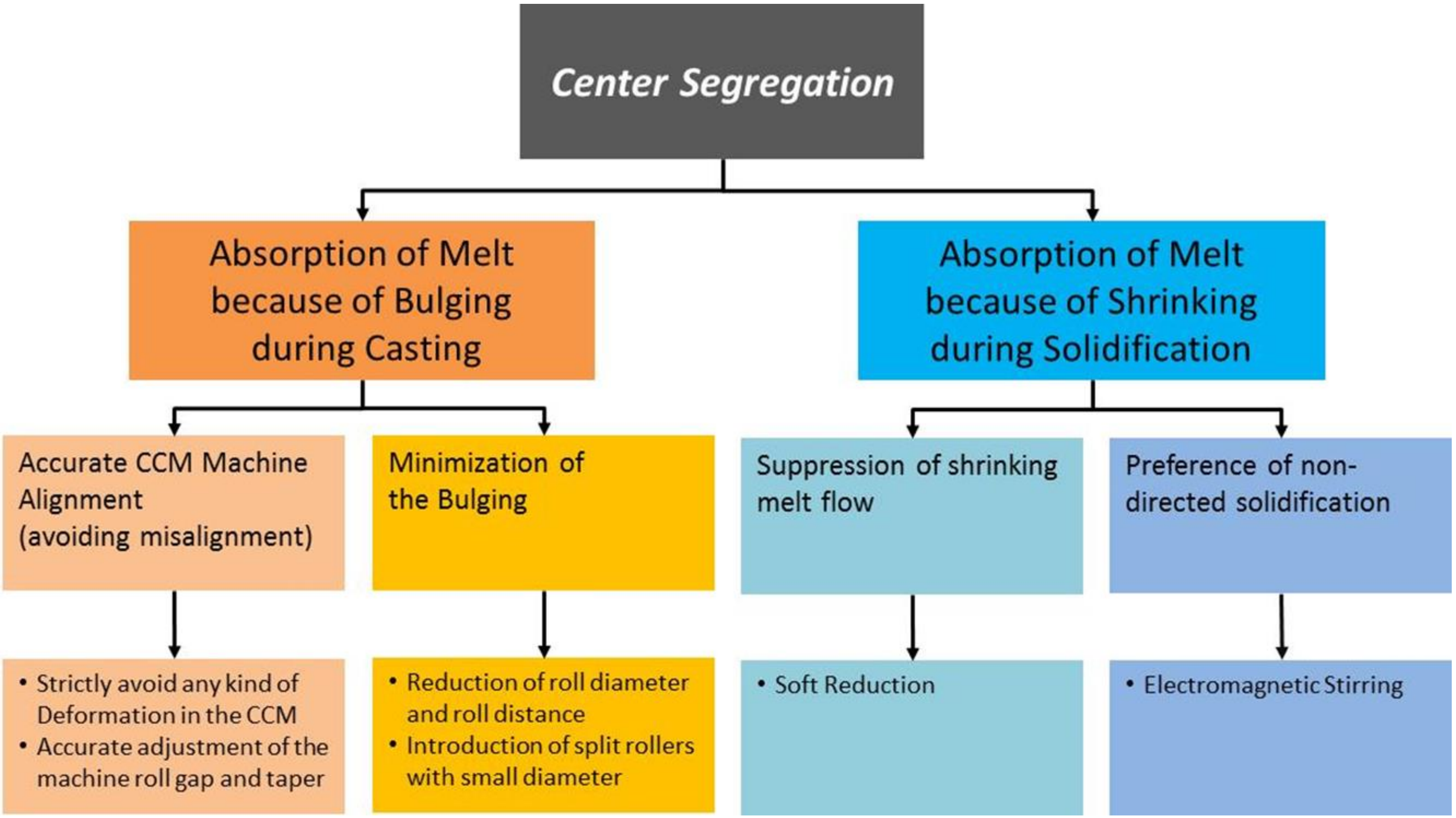
Example for Control Image Classification: **Center Line**



Class 1 | Class 2 | Class 3 | Class 4 | Class 5

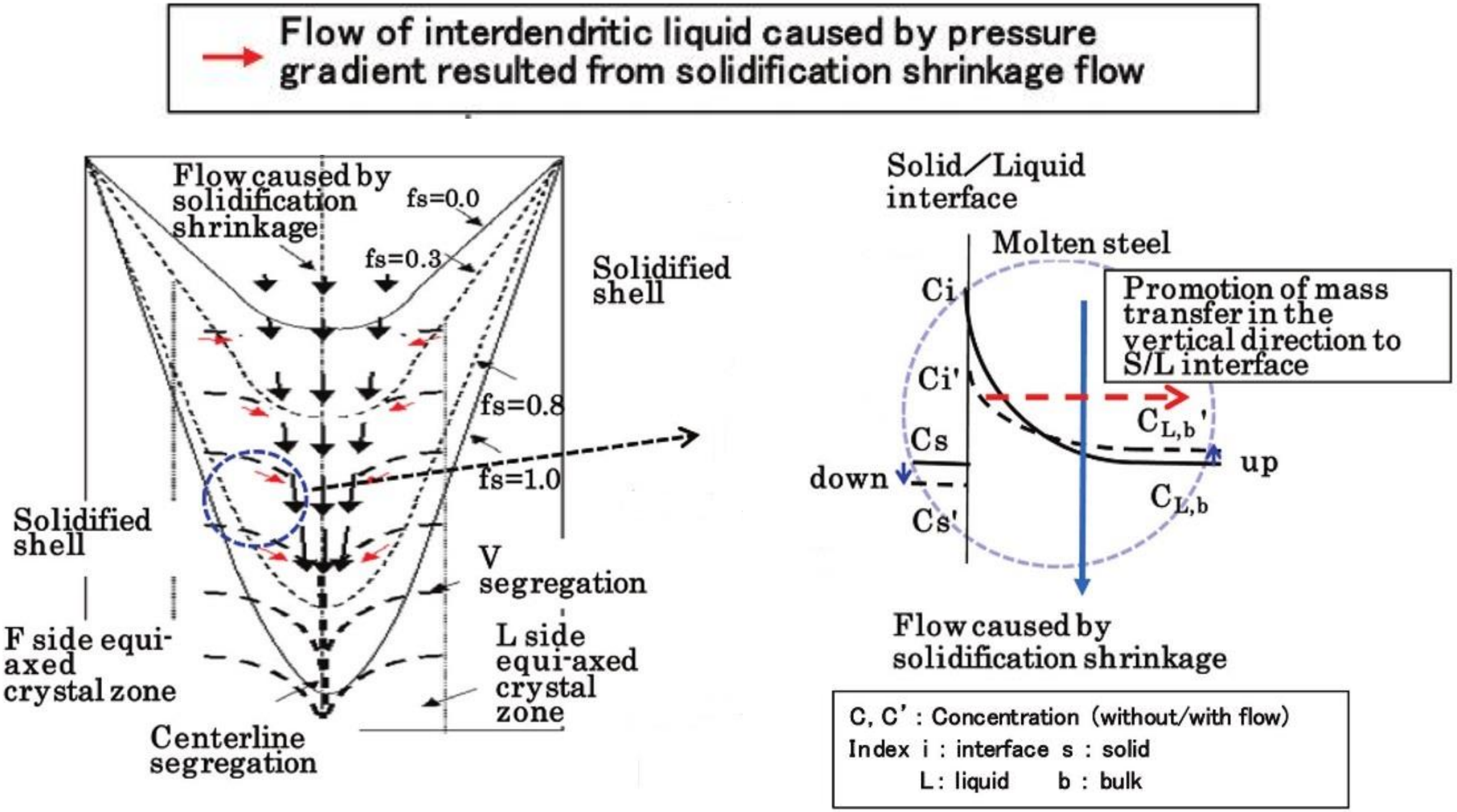
Various Classification Standards have been developed by the Steel Producing Companies available for Reference. The Quality Checks are carried out on Macro Etching Samples

Mechanism of Center Segregation in Cast Material (2 of 6)



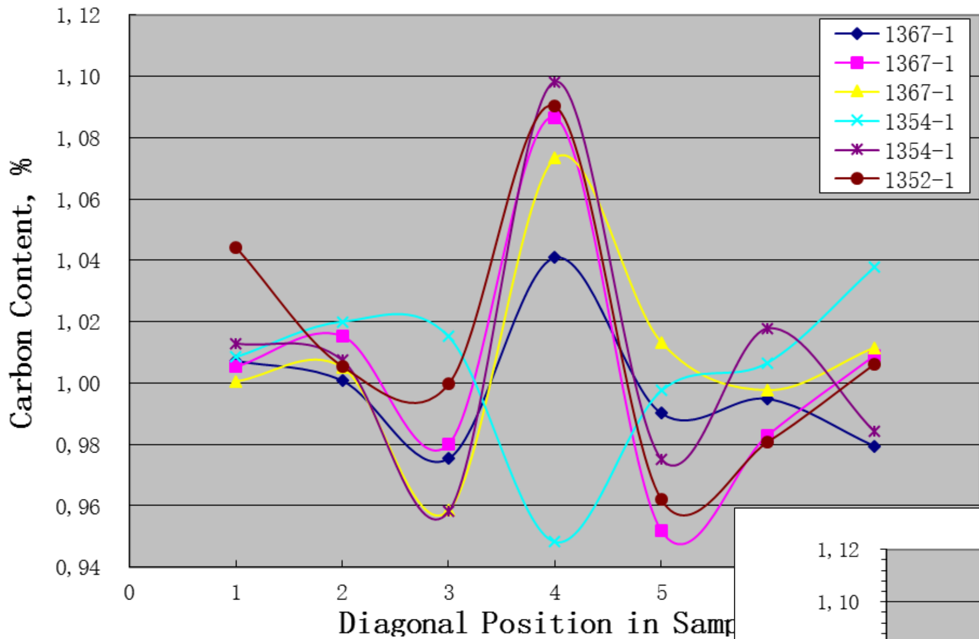
Mechanism of Center Segregation in Cast Material (3 of 6)

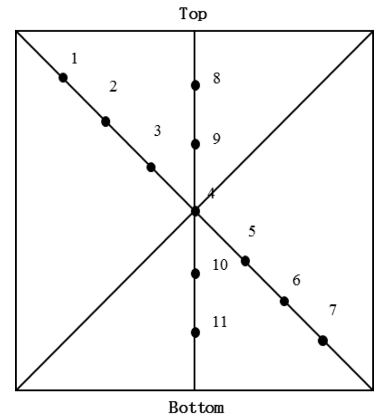
Simplified schematic of formation of V-segregation, centerline segregation and negative Macro-segregation near a center of cross section in a continuous cast bloom

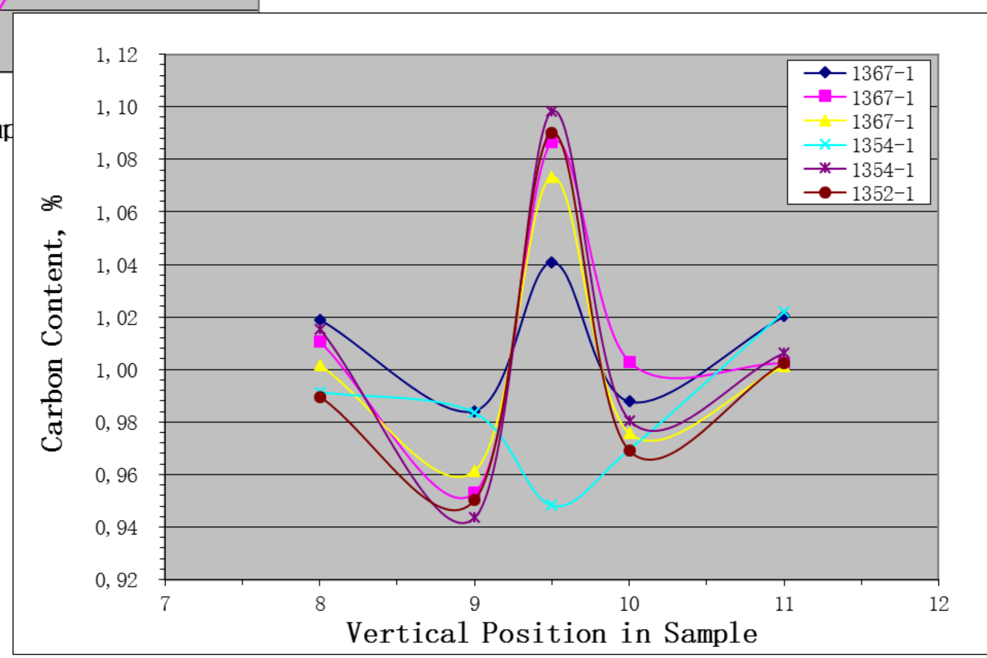


Source: Myazaki, M., Murao, T.: Nippon Steel Technical Report No. 104, August 2013

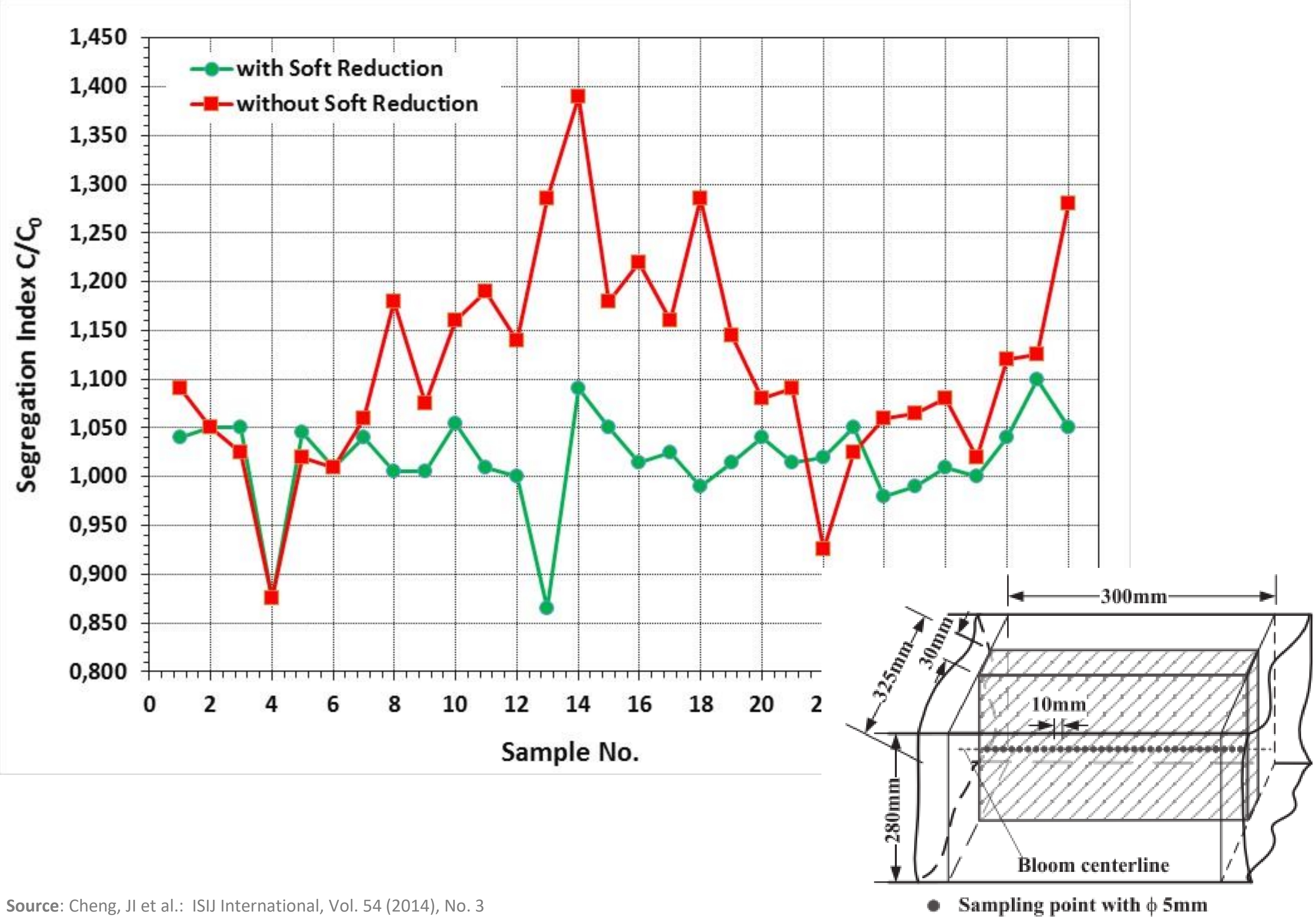
Example for Carbon Segregation at high Carbon Steel (0,80 – 0,84 %C) (4 of 6)







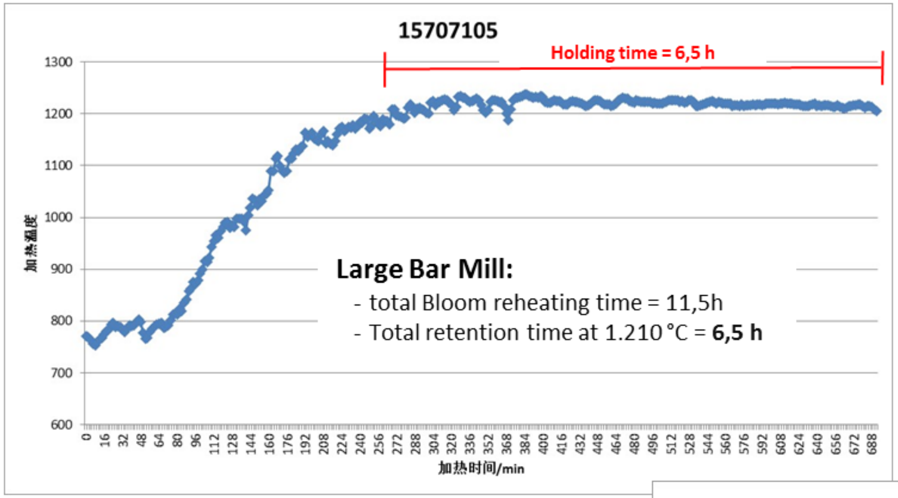
Optimization of Carbon Segregation by Soft Reduction of Blooms (5 of 6)



Source: Cheng, JI et al.: ISIJ International, Vol. 54 (2014), No. 3

Reheating Condition for Bearing Steel (6 of 6)

Reheating Condition in the XXX Rolling Mills (1 Heat, 85 t = 14,2 Blooms, 6,0 t)

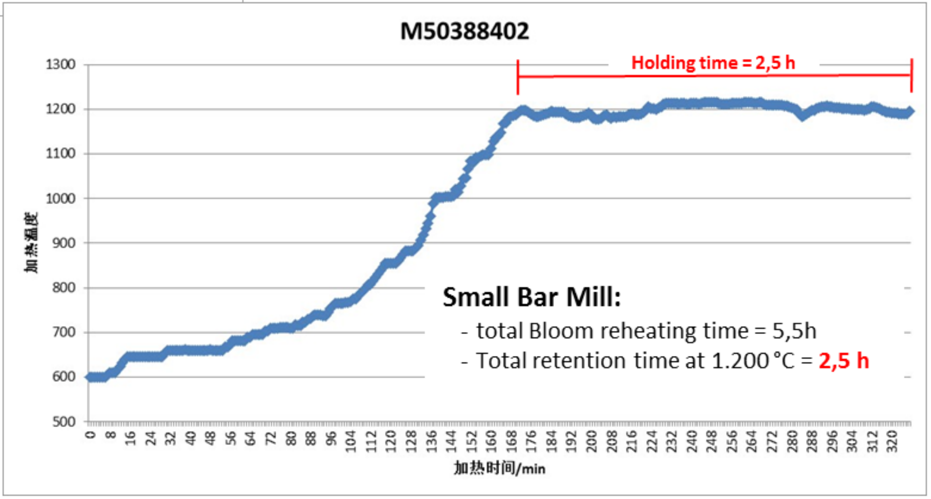


Large Bar Mill:

1 Bloom (□ 320 x 480 mm^2; 5,4m = 6,0t) =
2 Billets (□ 180 mm^2; 12m = 2,95t) =
3 Billets (□ 150 mm^2; 12m = 2,05t)

Small Bar Mill:

1 Billet (□ 180 mm2; 12m) = 2,95t)
= **20** Bars (Ø 55-65 mm; 7,0m =)



Rolled Bar Samples: 6 samples are taken from 4 bars of the heat, selection by purpose

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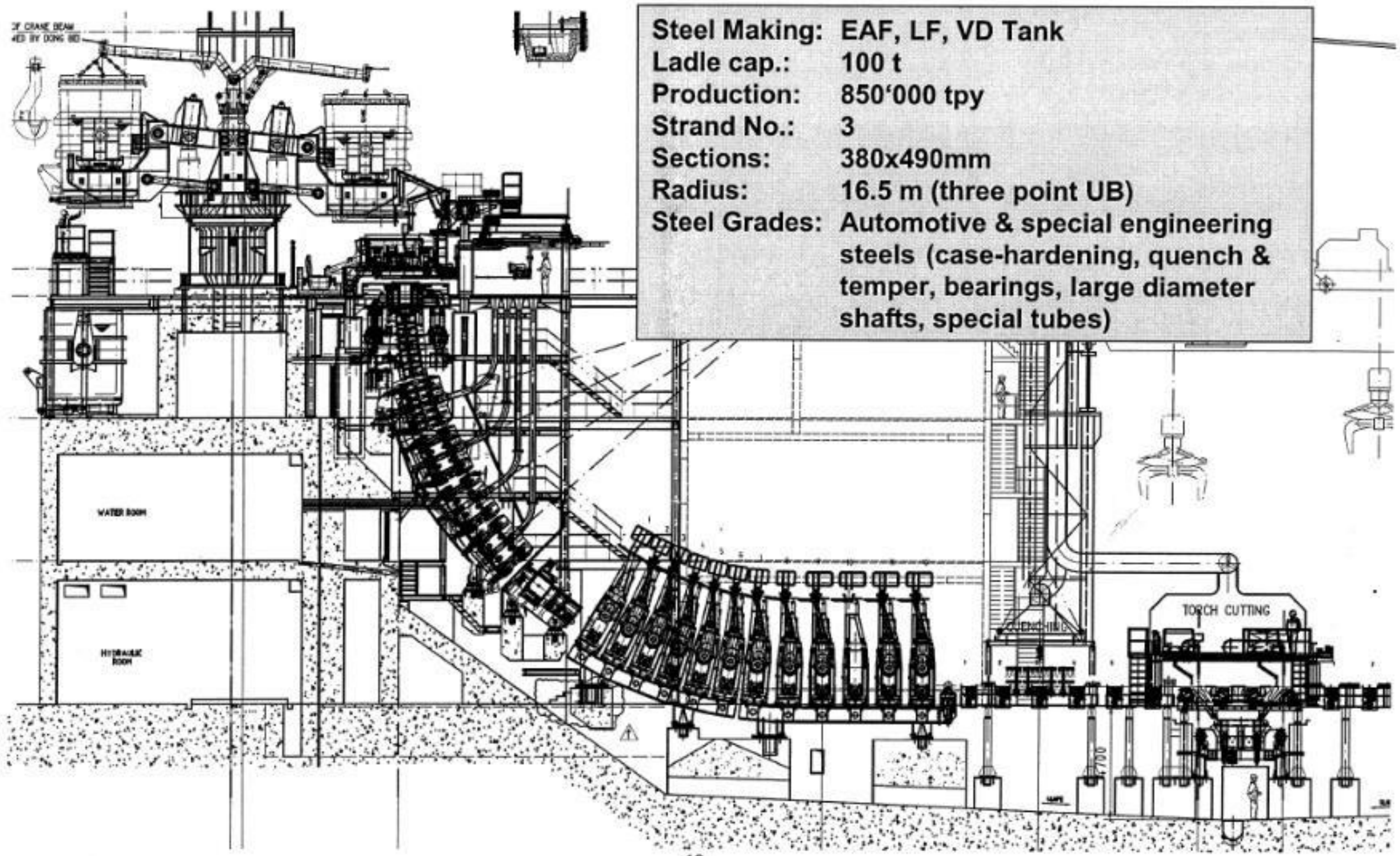
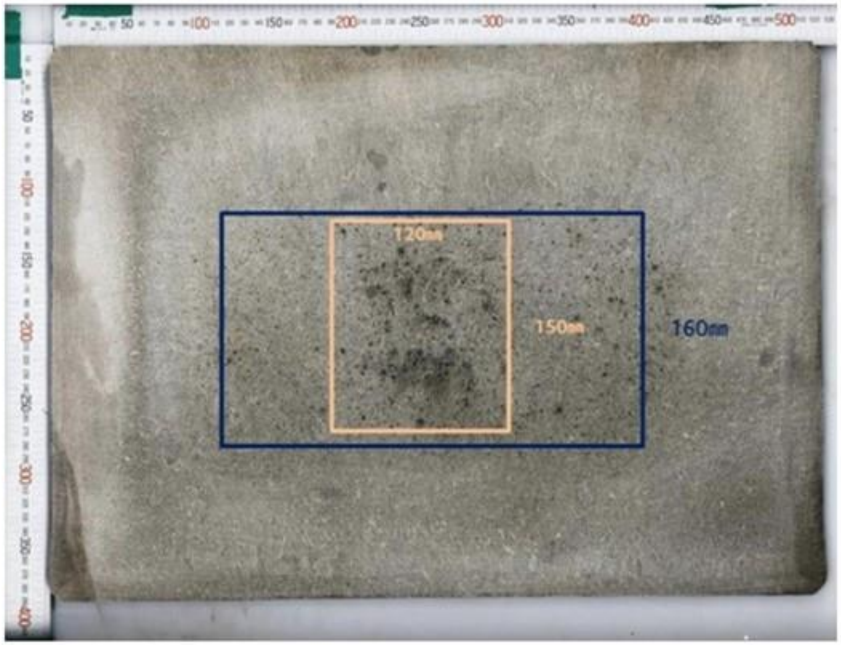
Typical Continuous Bloom Casting Machine Details



Source:

Macroetching Samples Bloom – Billet – Bar (SUJ2RI; C: 0,97 – 1,01 %; Cr: 1,45 – 1,51 %)

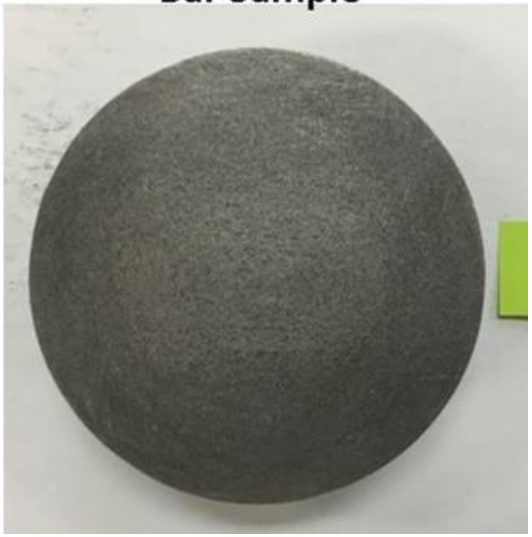
Transversal Sample



Billet Sample

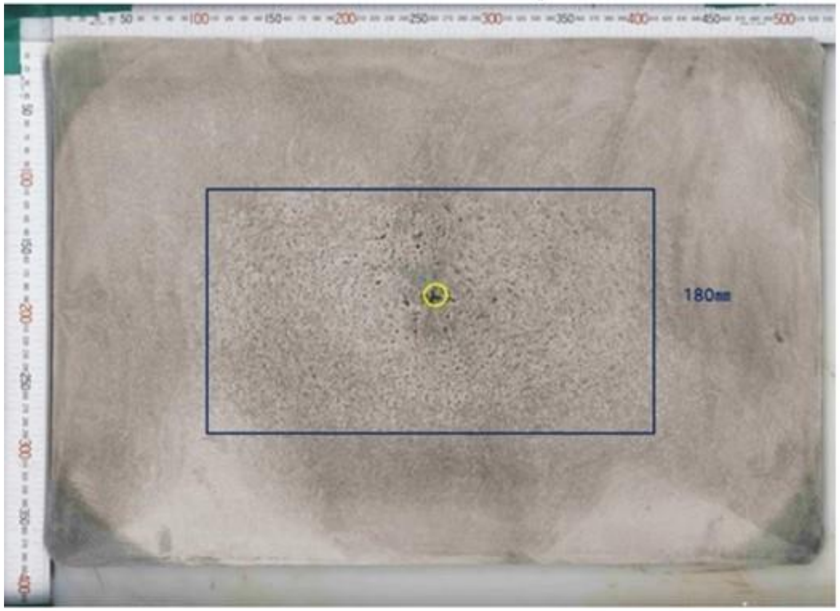
Longitudinal Sample

Bar Sample

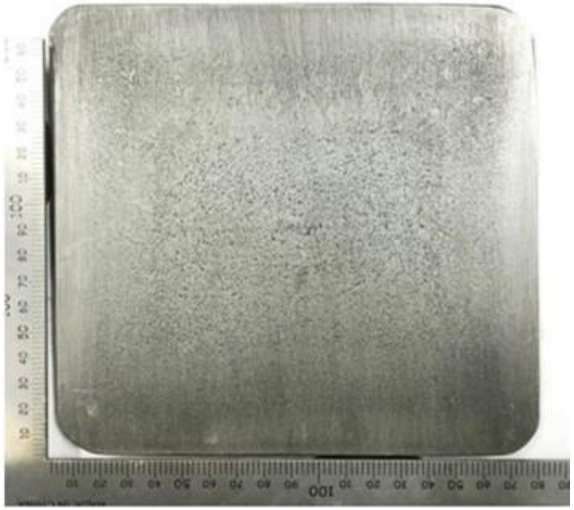


Macroetching Samples Bloom – Billet – Bar (44MNSIVS6 C: 0,41 – 0,44; Cr: 0,22 – 0,28 %)

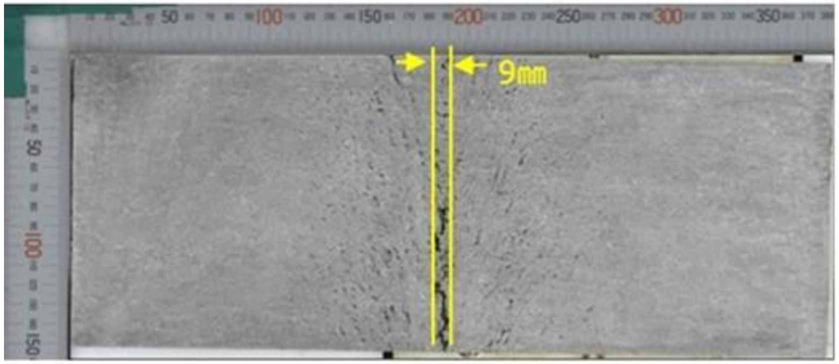
Transversal Sample



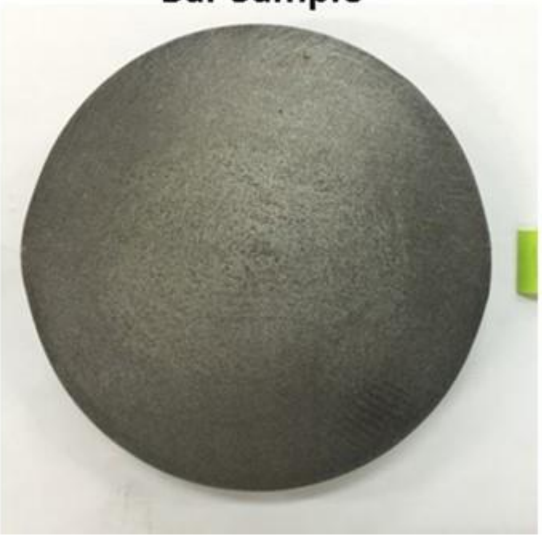
Billet Sample



Longitudinal Sample

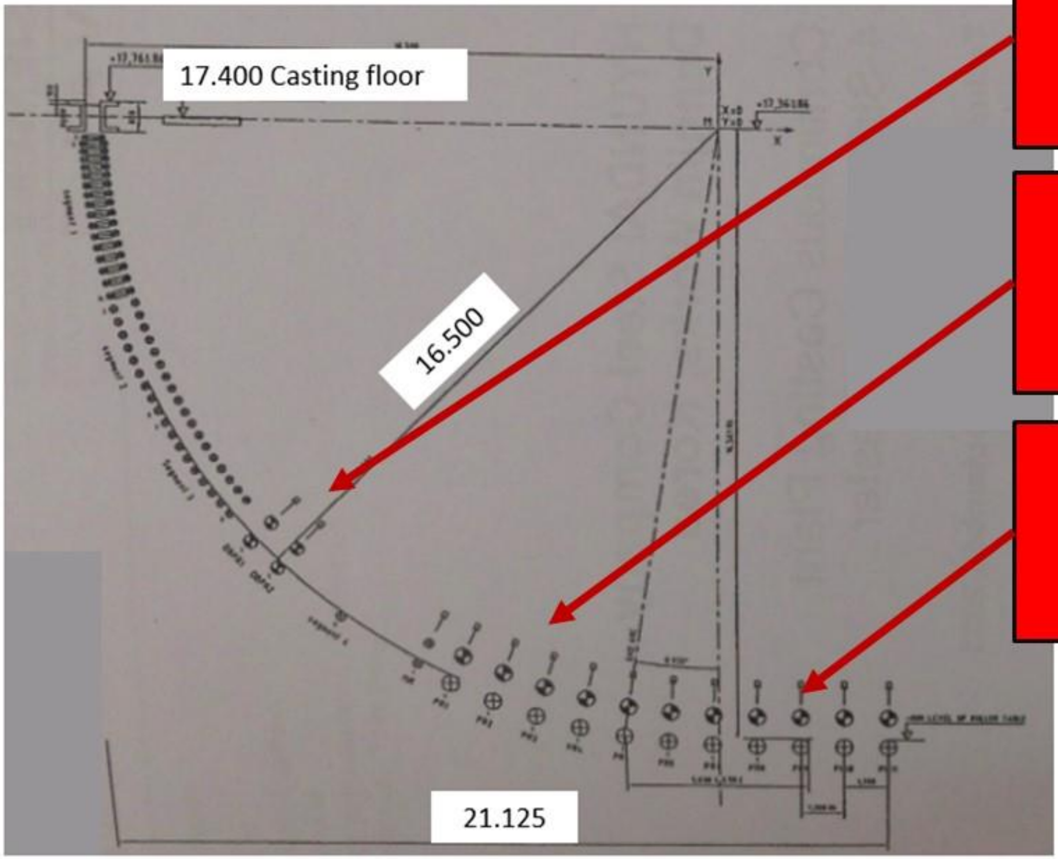


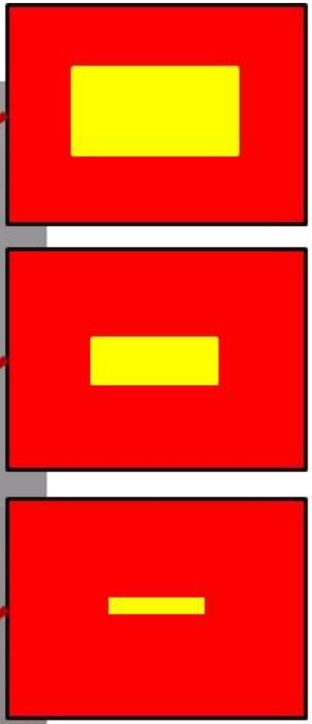
Bar Sample



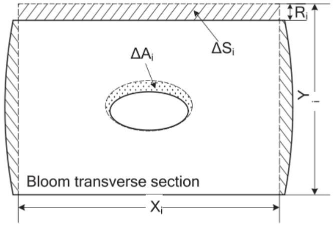
Soft Reduction Problematic with thick Blooms

Roller Diagram of a 16,5m Bloom Caster (390 x 530 mm²)





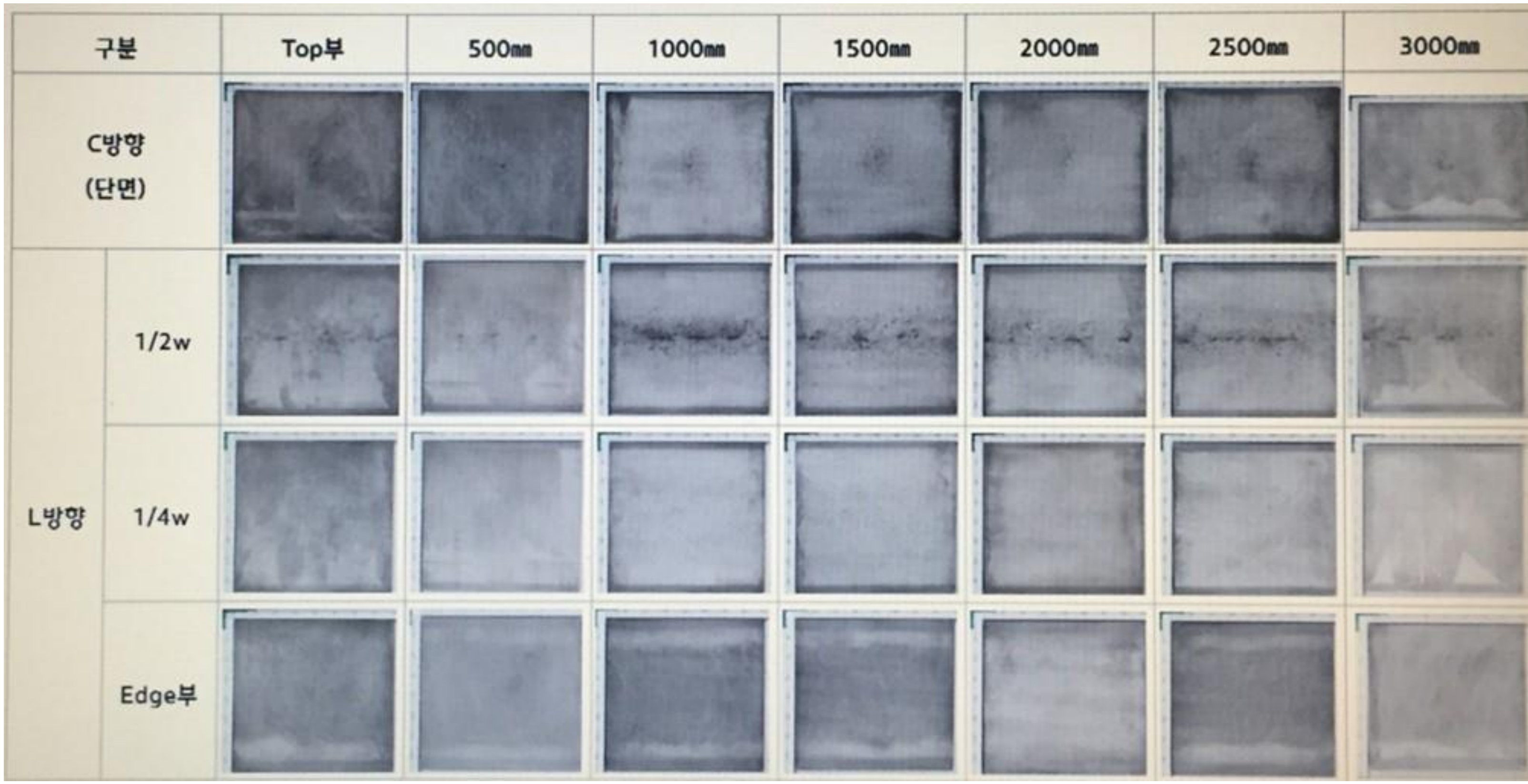
PR 1-7 bow
PR 8-11 horizontal



With a uniform solidification (shell growth) from all four sides as a result of uniform spray water cooling of the broad and narrow bloom sides the condition for a successful soft reduction of the liquid core become more and more difficult.

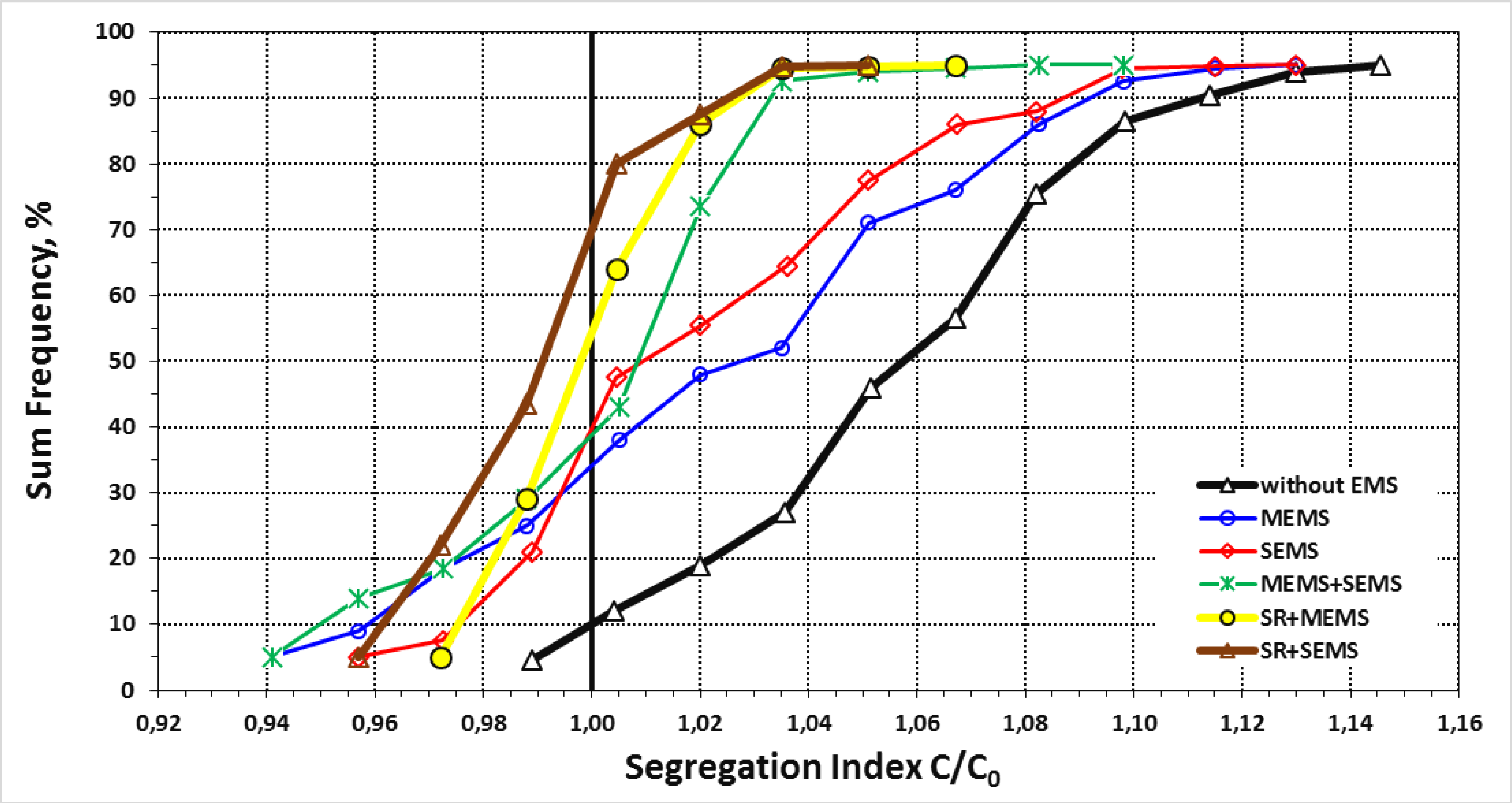
Reheating Problematic with thick Blooms

The samples show a Bloom inspected after reheating in the RHF of a LBM for six hours holding time at temperature > 1.200 °C (before rolling). The 1st row shows cross section images at different length, the other rows show longitudinal section images at different width of the bloom.



It becomes obvious that for this grade (44MnSiVS6) the center segregation from the continuous casting at ½ width could not be eliminated sufficiently in the furnace.

Segregation Coefficients with different Stirrer Positions and Soft Reduction



EMS = Electro Mangnetic Stirring M = Mold S = Strand SR = Soft Reduction

The graph shows the change in the center segregation index for one grade with application of different tools for solidification improvement. The best results are achieved with Soft Reduction + Mold EMS

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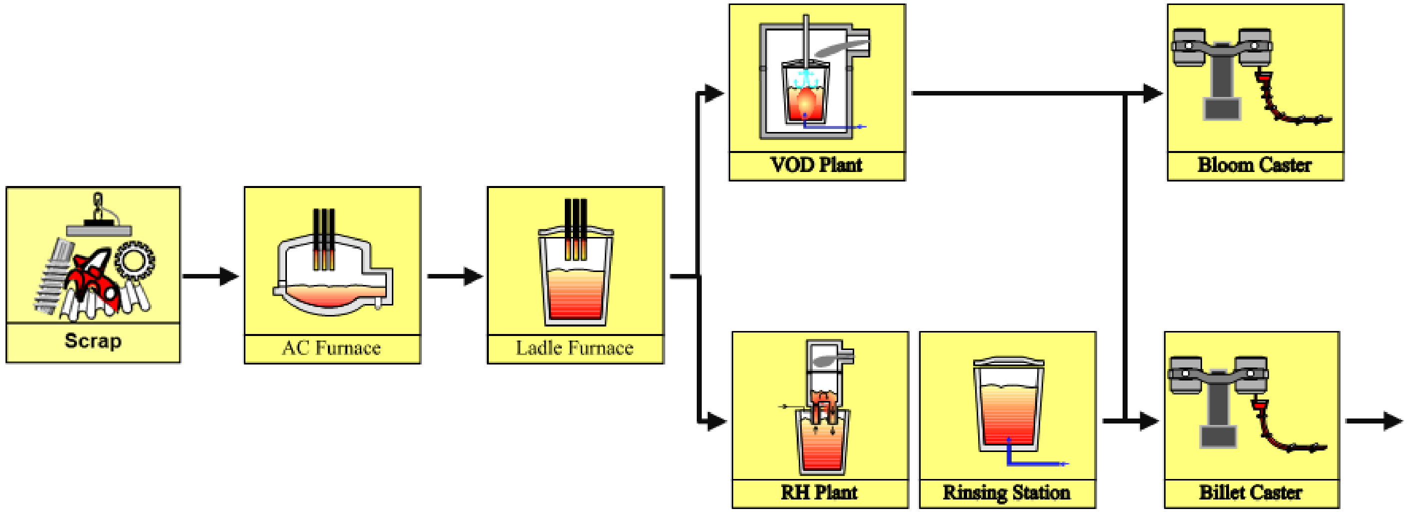
Typical Upstream Layout of a Engineered Steel (SBQ) Complex

Raw Materials → Melting → Refining → Cleanliness Improvement → Casting → Blooms to Rolling Mills

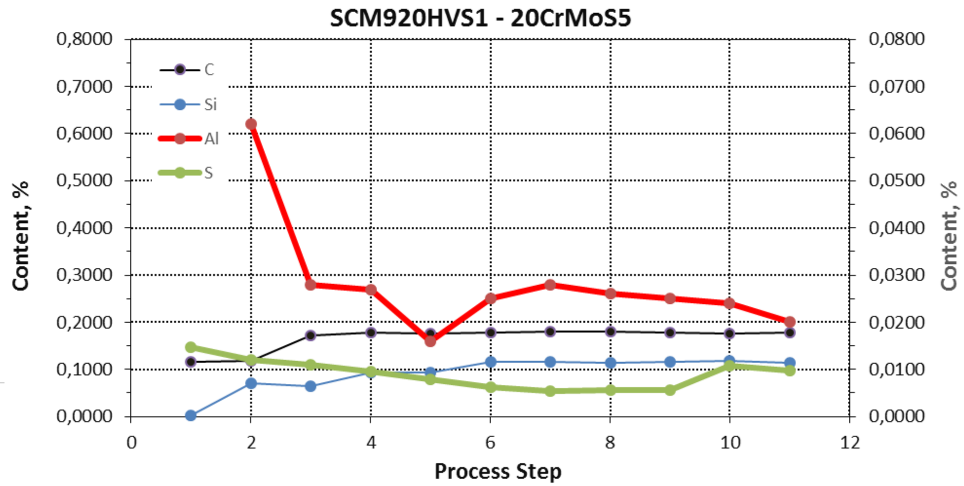


Typical Steelmaking Process Routes

Metallurgy: **Al-killed**

Grade: **SCM920HVS1 – 20CrMoS5**
Type: Quench & Tempering Steel
Group: T/M Gear
Application: Drive Pinion, Ring Gear, Pinion Gear, Lay Shaft, ...
Dimension: Ø 80-160, □ 180

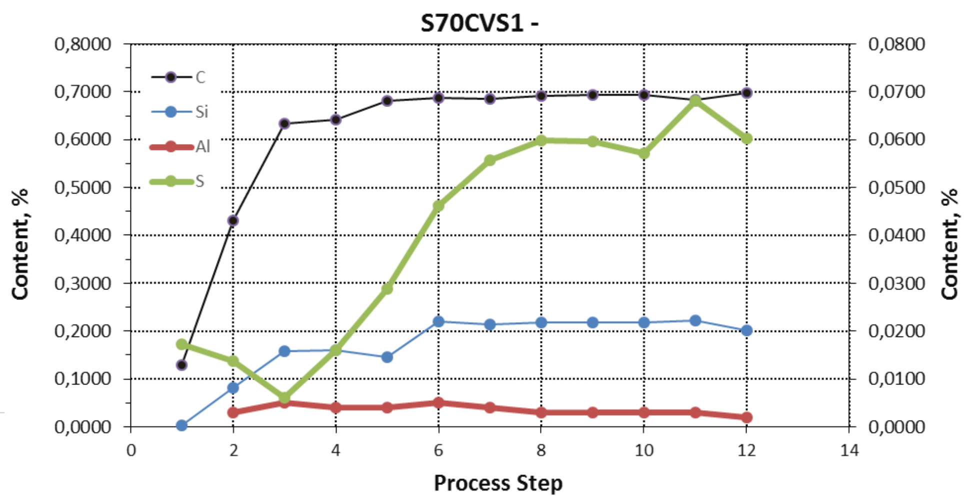
C	Si	Mn	P	S	T-Al	Ni	Cr	Mo	Nb	N
0,1700	0,0800	0,6800		0,0050	0,0100	0,0700	1,3000	0,5900	0,0150	100
0,1800	**0,1100**	**0,7000**		**0,0100**	**0,0250**	**0,1000**	**1,3200**	**0,6000**	**0,0200**	**130**
0,1900	0,1400	0,7200	0,0200	0,0200	0,0400	0,1300	1,3400	0,6100	0,0250	160



Metallurgy: **Si-killed**

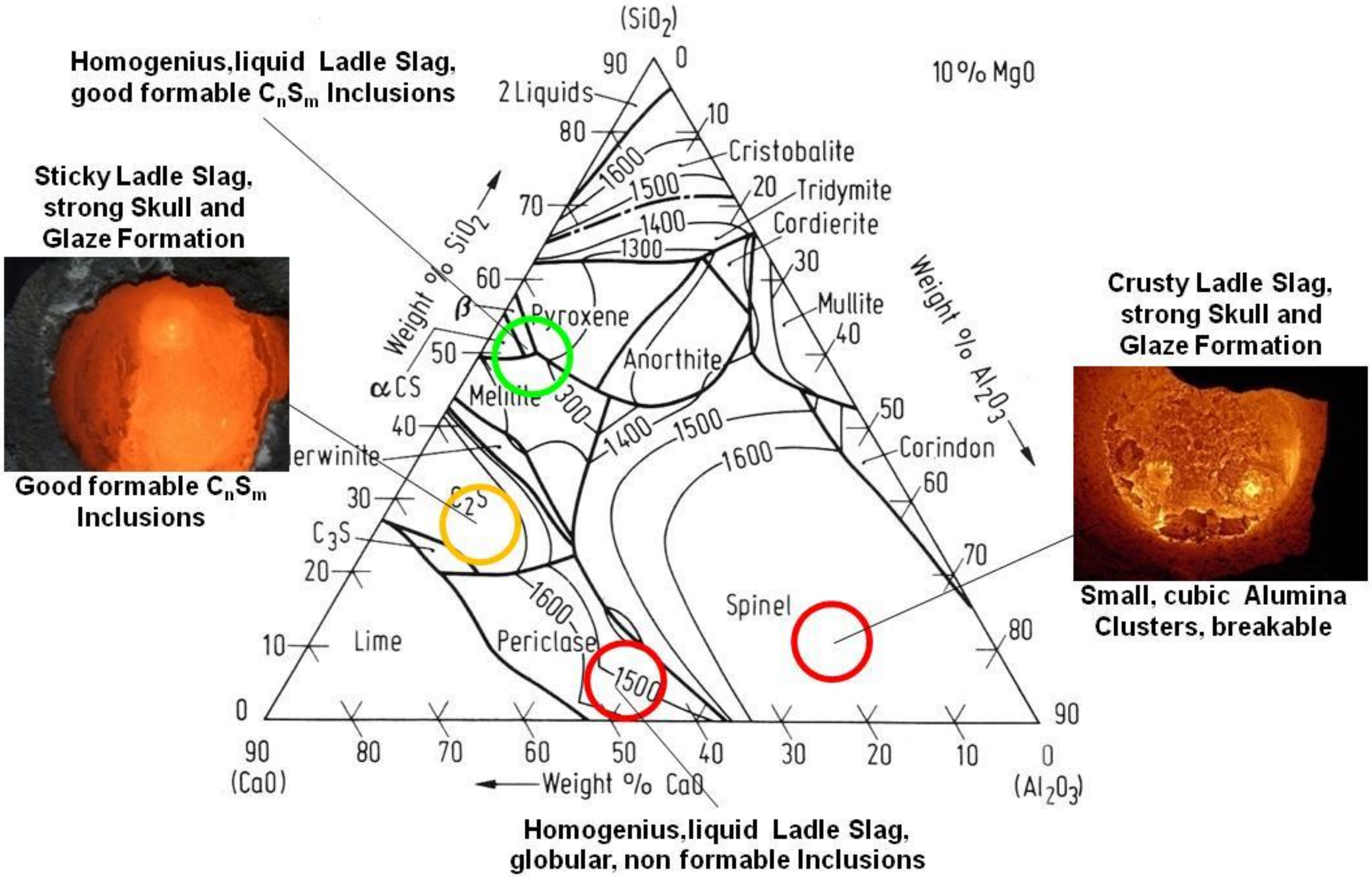
Grade: **S70CVS1 -**
Type: Press Hardening Steel (high strength)
Group: E/G Engine
Application: Crank Shafts, Conrod, Steering Knuckle, ...
Dimension: □ 180

C	Si	Mn	P	S	T-Al	Ni	Cr	Mo	V	N
0,6900	0,1900	0,4500	0,0150	0,0550		0,0600	0,1100		0,0330	90
0,7000	**0,2300**	**0,4900**	**0,0250**	**0,0600**		**0,0800**	**0,1400**		**0,0380**	**120**
0,7200	0,2700	0,5300	0,0400	0,0700	0,0100	0,1200	0,1700	0,0500	0,0430	150



Steel Refining Slag Compositions

Non metallic Inclusions and Ladle Slag Composition



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Conclusions

- **Future trends in Automotive Markets will continue to increase in passenger safety and comfort with negative impact on vehicle weight and fuel efficiency.**
- **Car manufacturers differentiate their customer services by longer warranties.**
- **“Long Life Cycle” and “Zero Defect” approaches continue to create pressure on the product performance of part and material suppliers.**
- **New forming and manufacturing technologies require more sophisticated products.**
- **New an better performing testing methods for steel semi-finished products lead to more detections.**
- **Lean and highly stressed applications for automotive parts draw the attention to inner quality of steel materials.**
- **Production of long steel products in the future requires increasing focus on steel cleanliness as well as internal quality in terms of cracks and avoiding segregations.**
- **Small product dimensions are less critical compared to bigger and huge dimensions.**

Thank You very much for Your Attention

I appreciate your comments and questions