The influence of Composition on the Cast Microstructure for Different Casting Technologies

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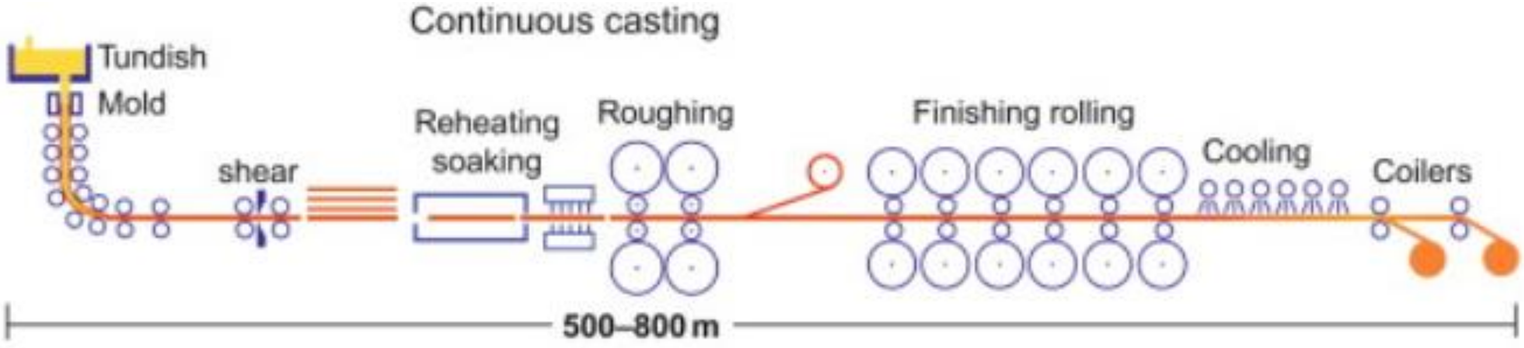
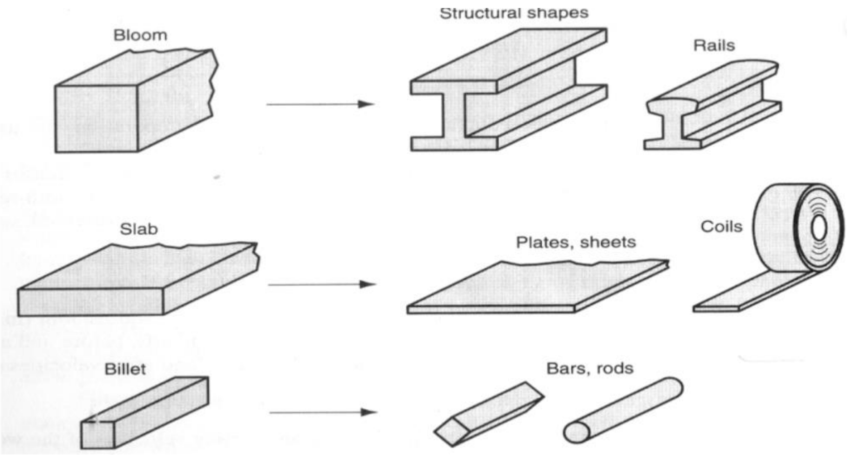
How is steel currently cast?

Continuous Casting



Conventional slab caster [1]

Conventional continuous caster [2]



Casting of liquid metal into blooms, billets or slabs [3]

Advantages:

- High levels of productions.
- Wide range of shapes.

Disadvantages:

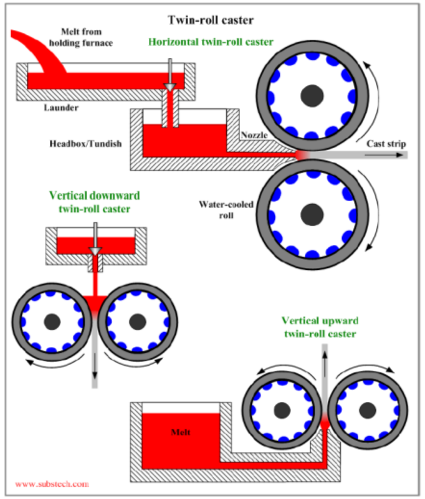
- Requires a lot of rolling.
- Some steel grades difficult to cast.

[1] S. Louhenkilpi In: Treatise on Process Metallurgy, edited by S. Seetharaman Elsevier 2014
[2] Bureau, M. (2021) Continuous casting of steel- overview, Metal World Insight.
[3] (1970) Operaciones de conformado de metales. metal shaping., Operaciones de conformado de metales. Metal Shaping.

Potential future of steel casting

Near net shape casting (NNSC)

[1] Twin Roll Caster



Advantages:

- Energy reduction in thermomechanical processing.
- Semi-finished products close to desired final geometry.
- Casting of 'new exotic' steels.

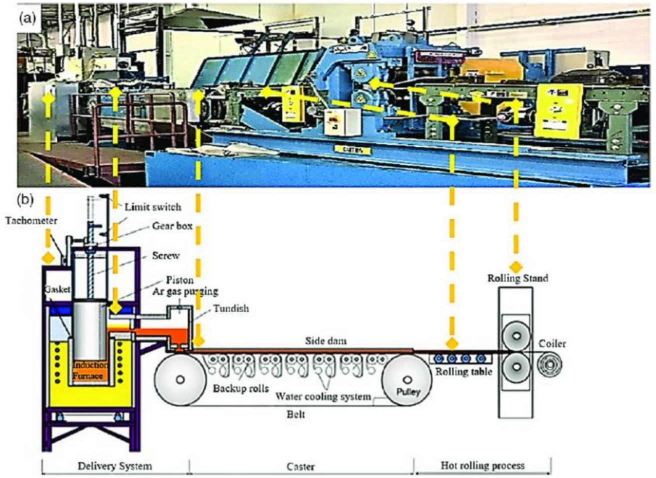
Disadvantages:

- Low production volumes of steel grades.

Differences:

- Microstructure and segregation.

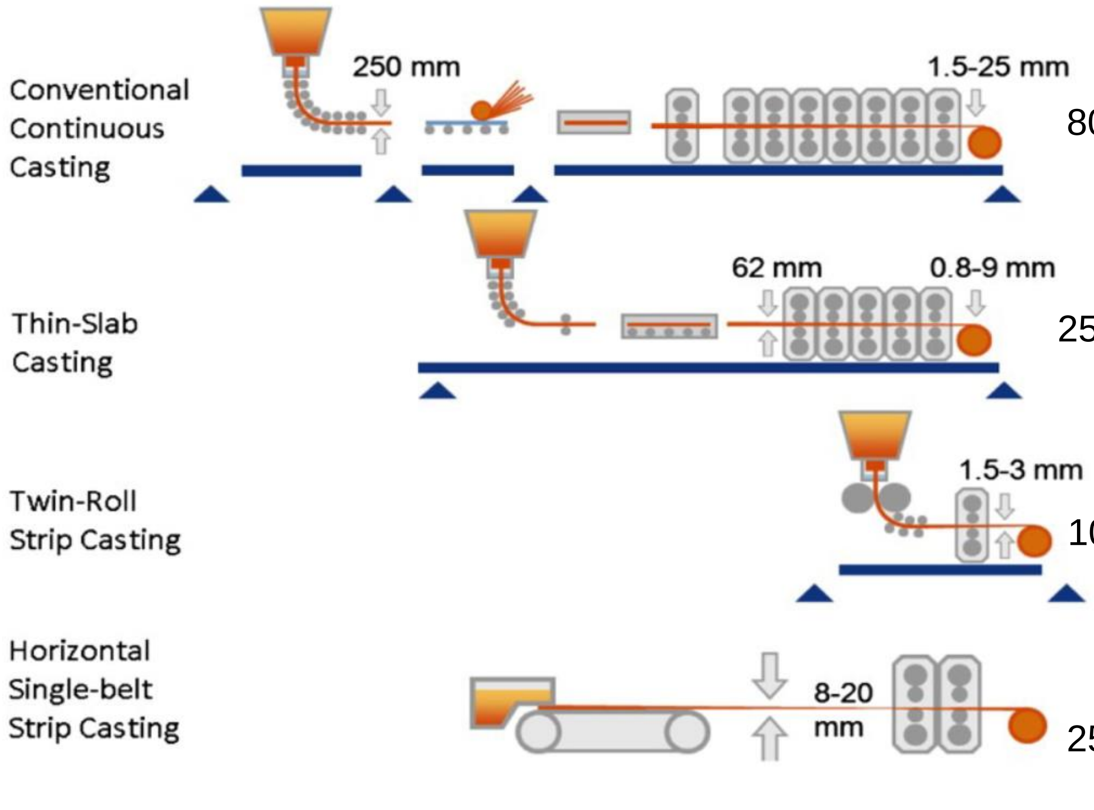
[1] Horizontal Single Belt Caster (Germany)



[1] Kopeliovich, D., 2022. Continuous casting in traveling mold [SubsTech].

What are the different casting technologies?

Near Net Shape Casting



Different Casting Technologies process layout [1]

Lengths of Casters:

800 m

250 m

100 m

25 m

Examples of where technologies are being currently used:

UK (TATA Steel – Port Talbot)
Cooling rate → 0.6 ℃/s

Netherlands (TATA Steel Ijmuiden)
Cooling rate → 10 ℃/s

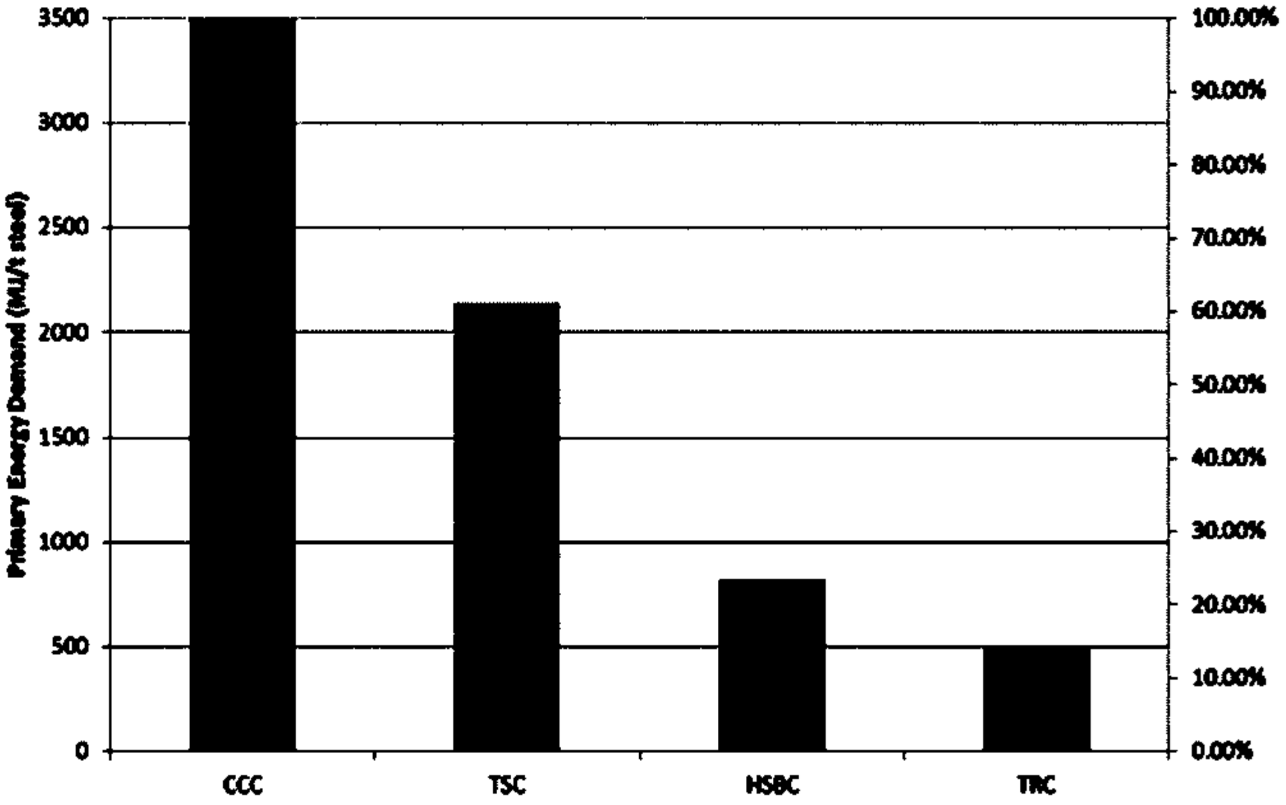
USA (Nucor – only for certain grades of steel)
Cooling rate → 723 ℃/s

Germany (Salzgitter – for small range of grades)
Cooling rate → 50 ℃/s

[1] Guthrie, R. I. L. and M. M. Isac (2016). "Conventional and near net shape casting options for steel sheet." Ironmaking & Steelmaking 43(9): 650-658.

Casting technologies – Energy considerations

Casting Technologies – Overview



Energy consumption estimate of 1 tonne of strip steel [1]

Key features:

CCC – Slowest cooling rates, requires a lot of rolling. Some steel grades difficult to cast.

TSC – Slow cooling rates, requires some rolling (semi-finished products). Some steel grades difficult to cast.

HSBC – Fast cooling rates, doesn't require much rolling.

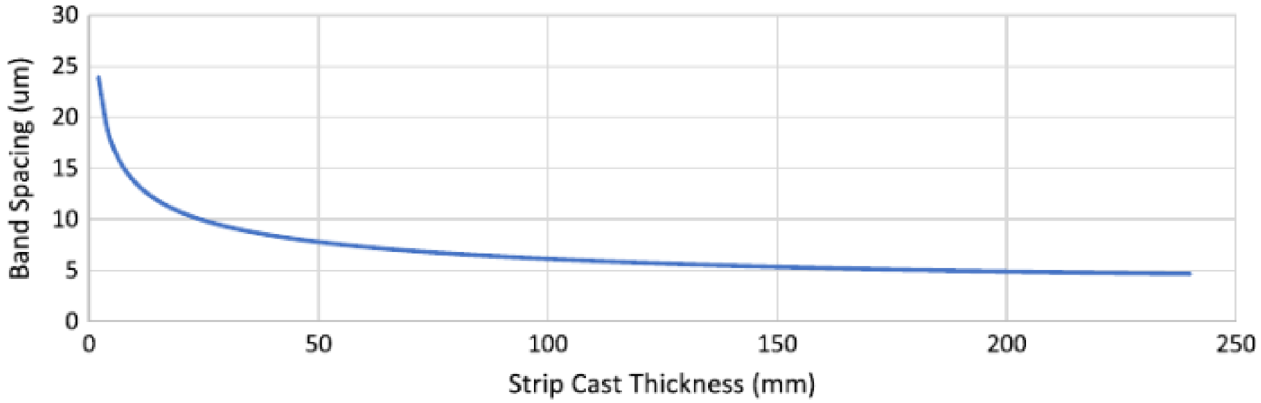
TRC – Fast cooling rates, doesn't require any hot rolling.

[1] Guthrie, R. I. L. and M. M. Isac (2016). "Conventional and near net shape casting options for steel sheet." Ironmaking & Steelmaking 43(9): 650-658.

Why study segregation?

Segregation can have many knock-on effects. For example:

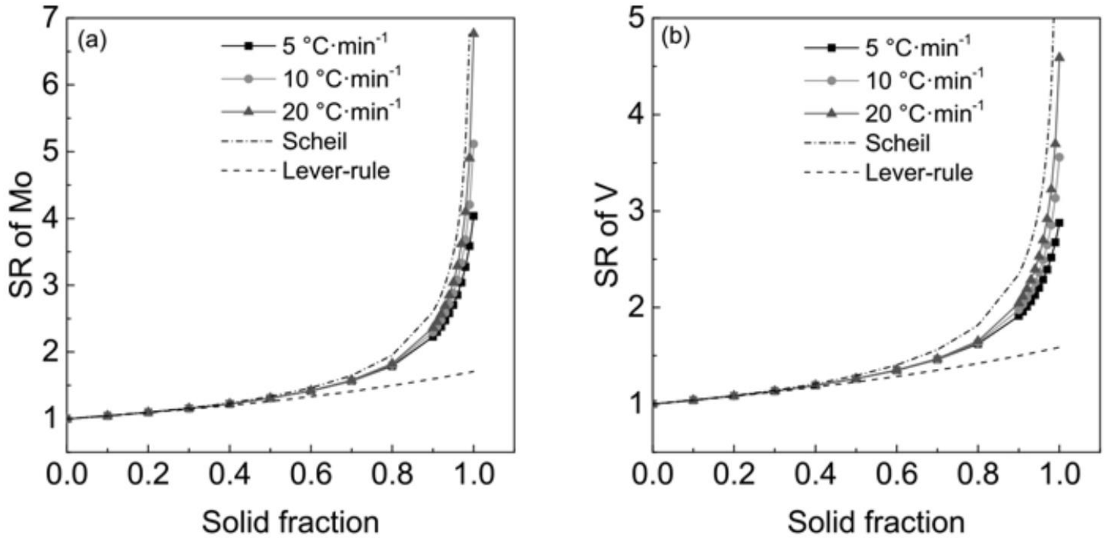
The band spacing for example will change with product thickness. Thinner casts produced will have a larger band spacing compared to thick cast material after rolling to the same final product thickness, as the reduction level has a more dominant influence than the secondary dendrite arm spacing for NNSC. [1]



Band spacing of DP800 strip produced by varying casting thicknesses [1]

Segregation is important because it affects local microstructural development, such as:

- Local number densities of microalloying precipitates in interdendritic and dendritic regions
- Potential to form inclusions or primary carbides in interdendritic regions.
- Banded microstructures in rolled condition



Cooling rate effect on segregation ratio, SR [2]

[1] C. Slater and C. Davis (2020) "Near Net Shape Casting: Is It Possible to Cast Too Thin?" Metallurgical and Materials Transactions B 51(6): 2532-2541.
[2] M. Mao, H. Guo, F. Wang and X. Sun (2019) "Effect of Cooling Rate on the Solidification Microstructure and Characteristics of Primary Carbides in H13 Steel" ISIJ International 59(5): 848-857.

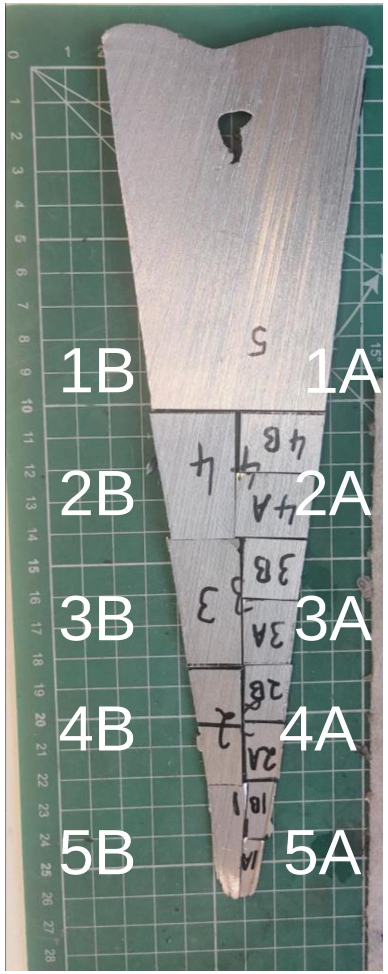
Materials and Casting

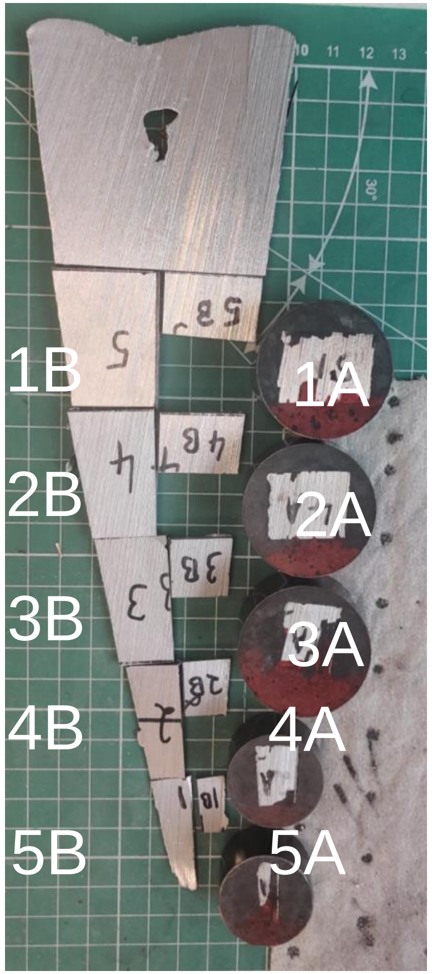
- The two different steel grades investigated are DP800 (rectangular mould) and S275 (wedge mould).
- A DP800 ingot was cast into a 30mm wide mould.
- The notable difference for these two compositions is the level of Mn content.

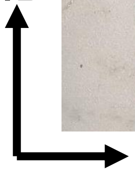
Wedge Mould cast

	C	Mn	Si	S	P	Cr	Al	Nb	Fe
S275 (Wedge Mould)	0.15	0.8	0.1	0.05	0.04	-	-	-	Balance
DP800 (Rectangular Mould)	0.135	1.82	0.265	0.003	0.005	0.535	0.008	0.026	Balance

Sectioning and mounting of samples







- Images show where the sections were taken from the wedge mould and a numbering system adopted for each sample.

- Samples with numbering of 1A, 2A etc were used for SEM/EDX analysis. While samples with 1B, 2B etc were used for SDAS analysis.

Methodology

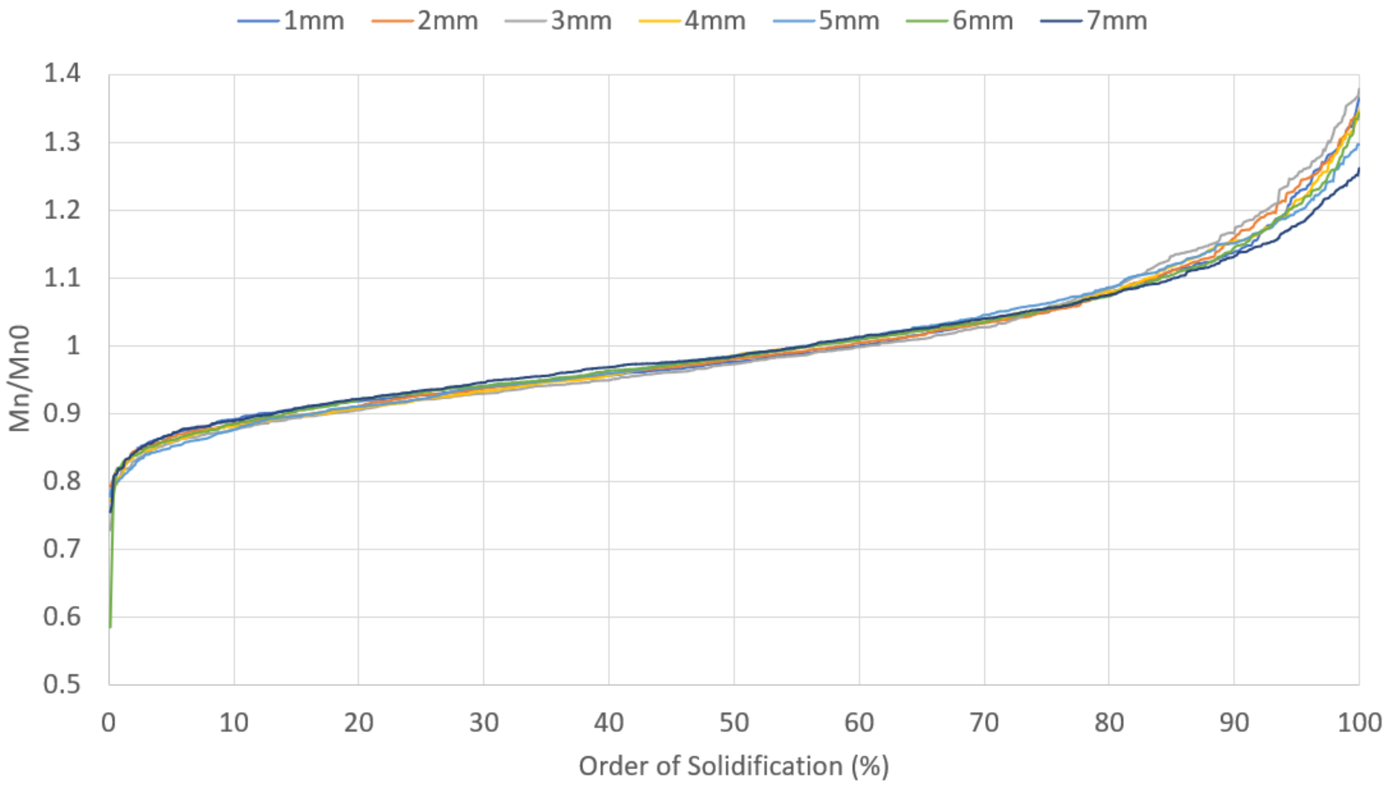
SEM/EDX Line scan analysis

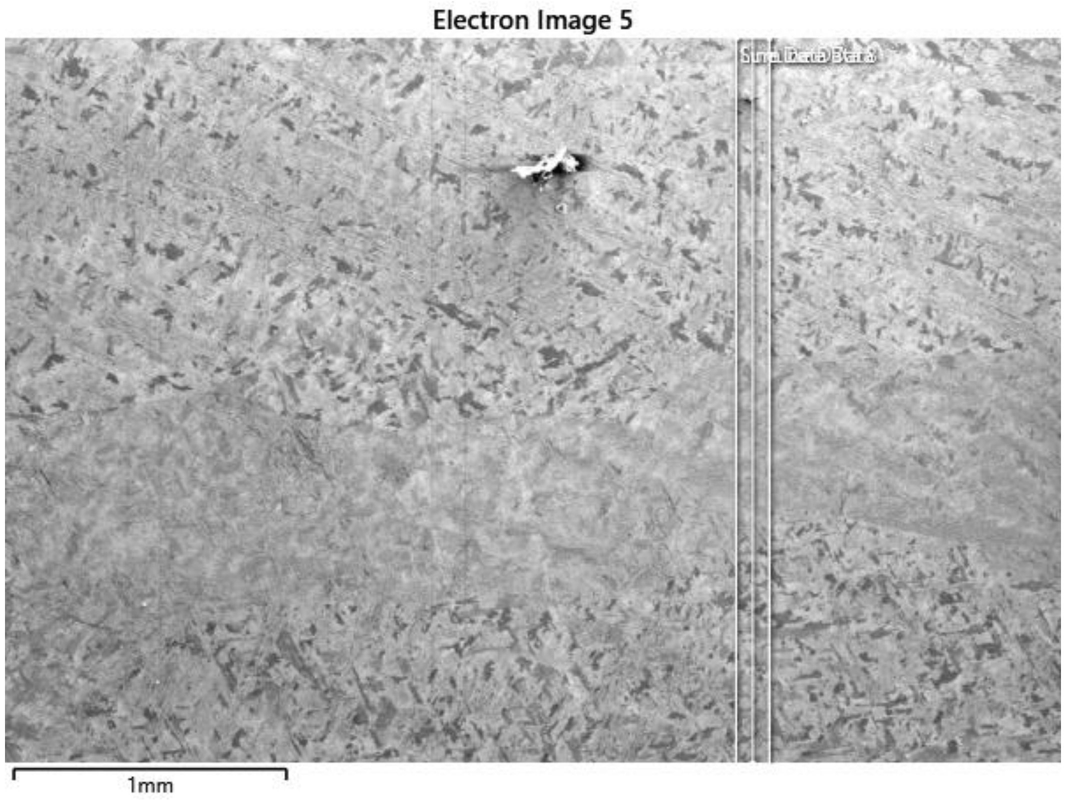
- Grid scan of 350x2 at spacing of 110 µm. This was ranked in terms of composition for Mn for compositional distribution for a given CR.
- The spacing between measured points is less than SDAS therefore data will sample both dendritic and interdendritic regions.
- Another parallel line scan was taken to measure 350 data points. This enables a total of 700 data points for the two-line scans per area map.

SDAS analysis

- Measurements of a minimum of 10 SDAS were taken for all compositions.
- The average SDAS measurements were taken for each sample.
- These SDAS measurements were repeated with through thickness to relate to the cooling rate.

Methodology

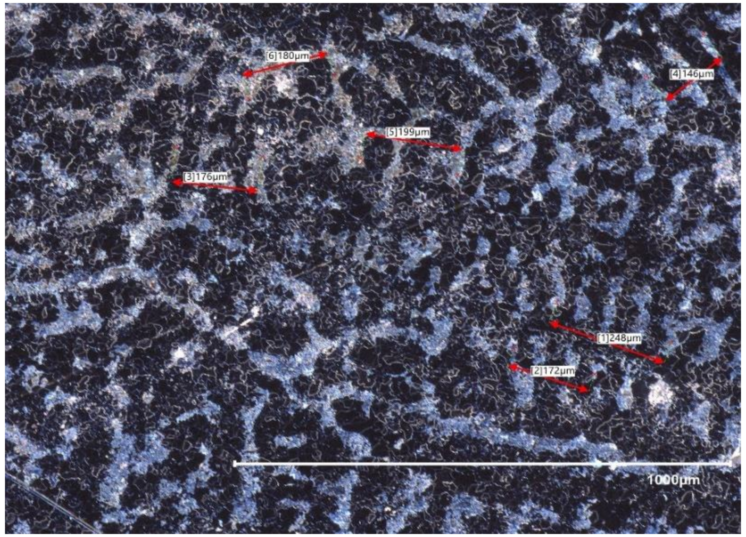




A ranking number system was utilised to investigate segregation ratio of Mn during solidification (Mn content over average bulk Mn composition). The segregation ratio was then defined as the local 95% percentile value / 5% percentile value.

$$SR = \frac{95th\ percentile\ value}{5th\ percentile\ value}$$

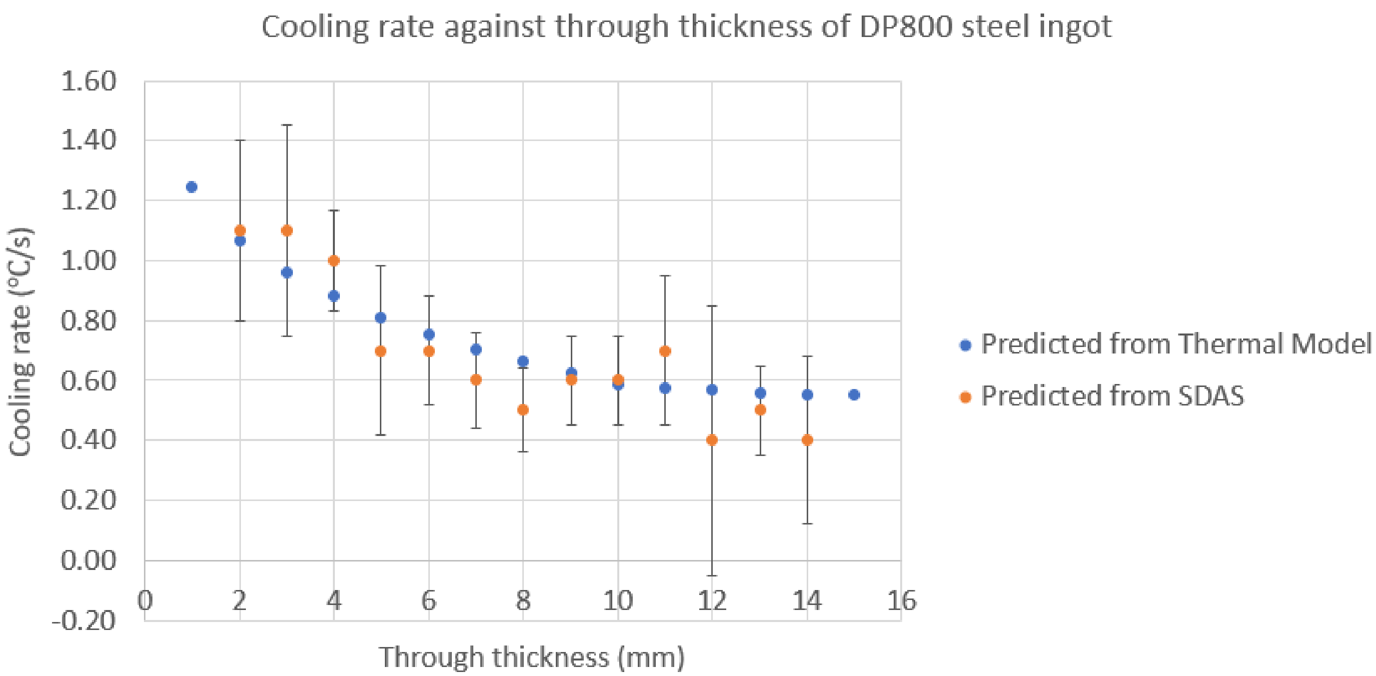
Predicted cooling rates



N.D

T.D

3mm away from left edge of as-cast block

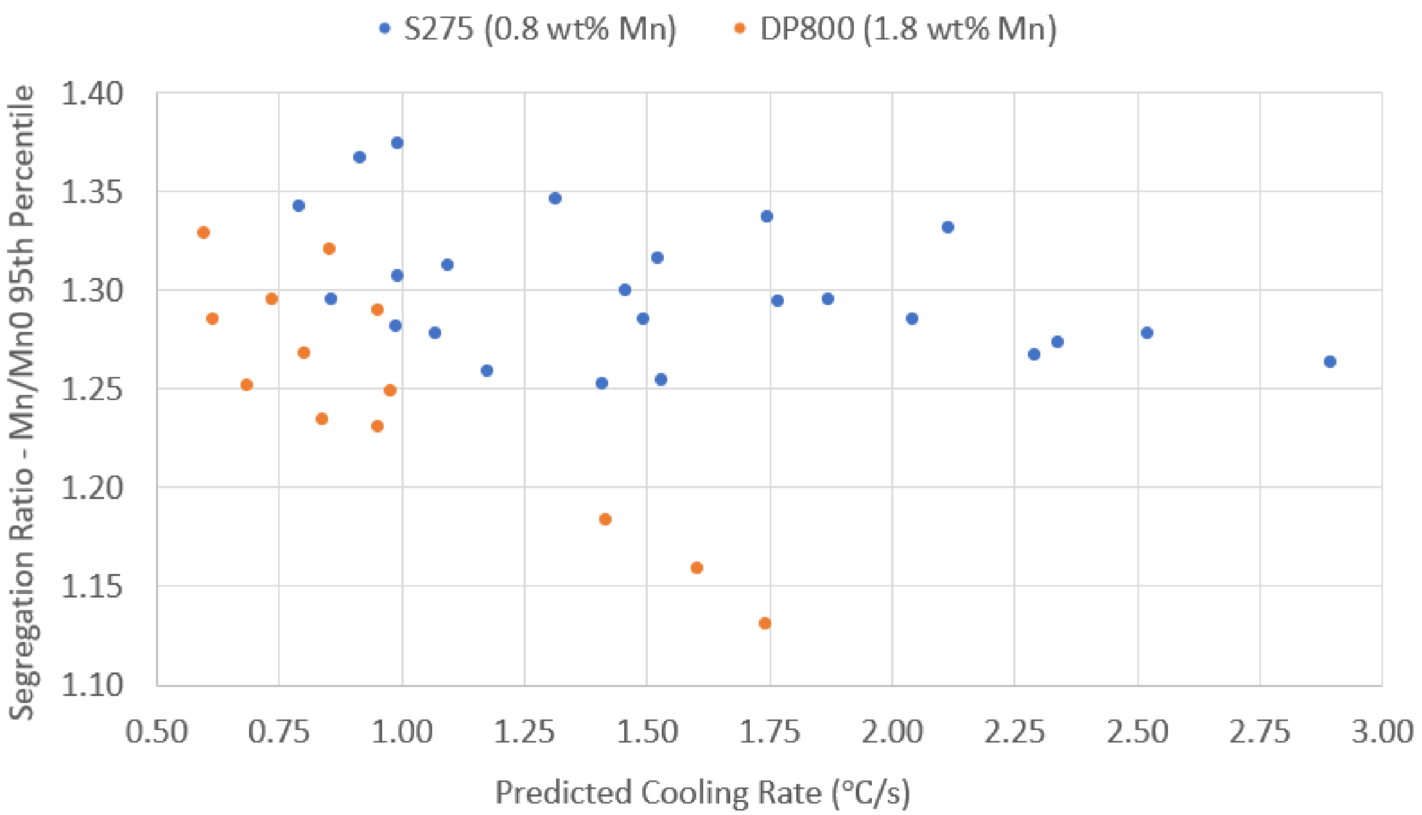


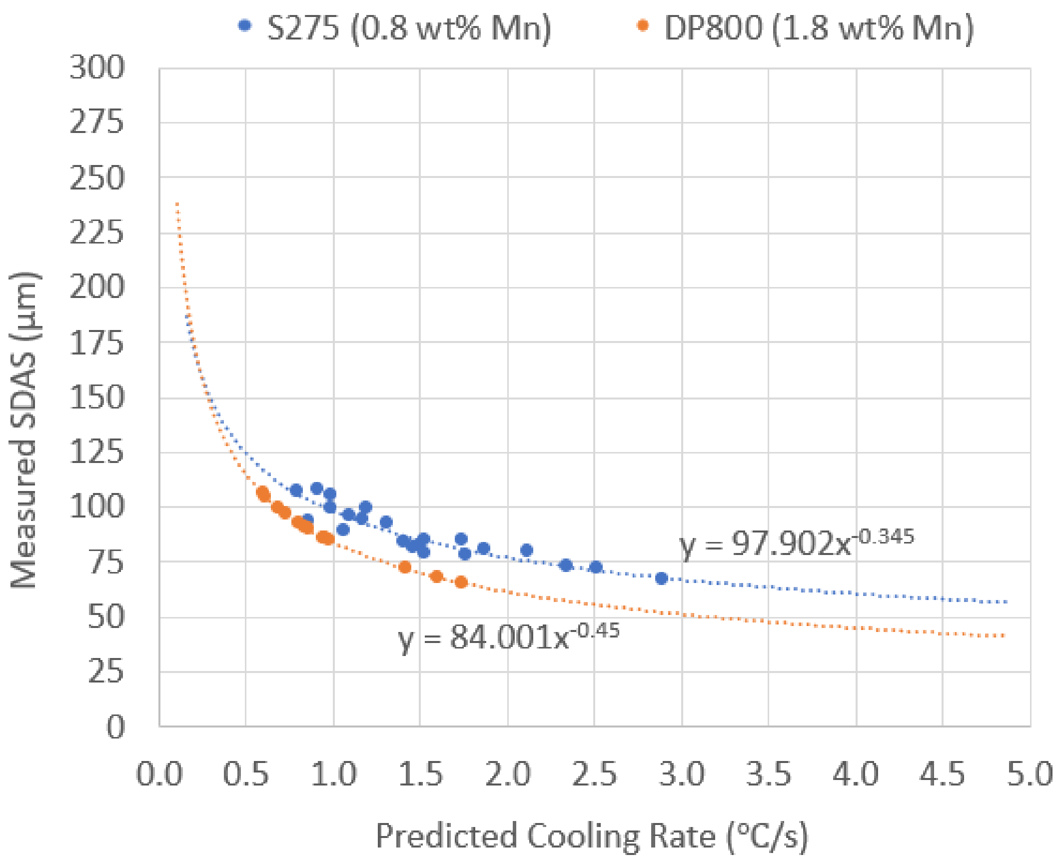
- The SDAS is measured through thickness, and this has been related to a rectangular mould to confirm the relationship and to validate a COMSOL model for cooling.
- The graph shows the cooling rate data for the DP800 steel ingot (from SDAS equation), and simulation cooling rate data obtained from COMSOL.
- Measured cooling rate data using SDAS equation → SDAS=84CR^-0.45 [1]

	DP800	S275
Liquidus (℃)	1515	1518
Solidus (℃)	1486	1463

[1] O. Volkova, H.-P. Heller and D. Janke (2003). " Microstructure and Cleanliness of Rapidly Solidified Steels" ISIJ International 43(11): 1724-1732.

S275 vs DP800 analysis

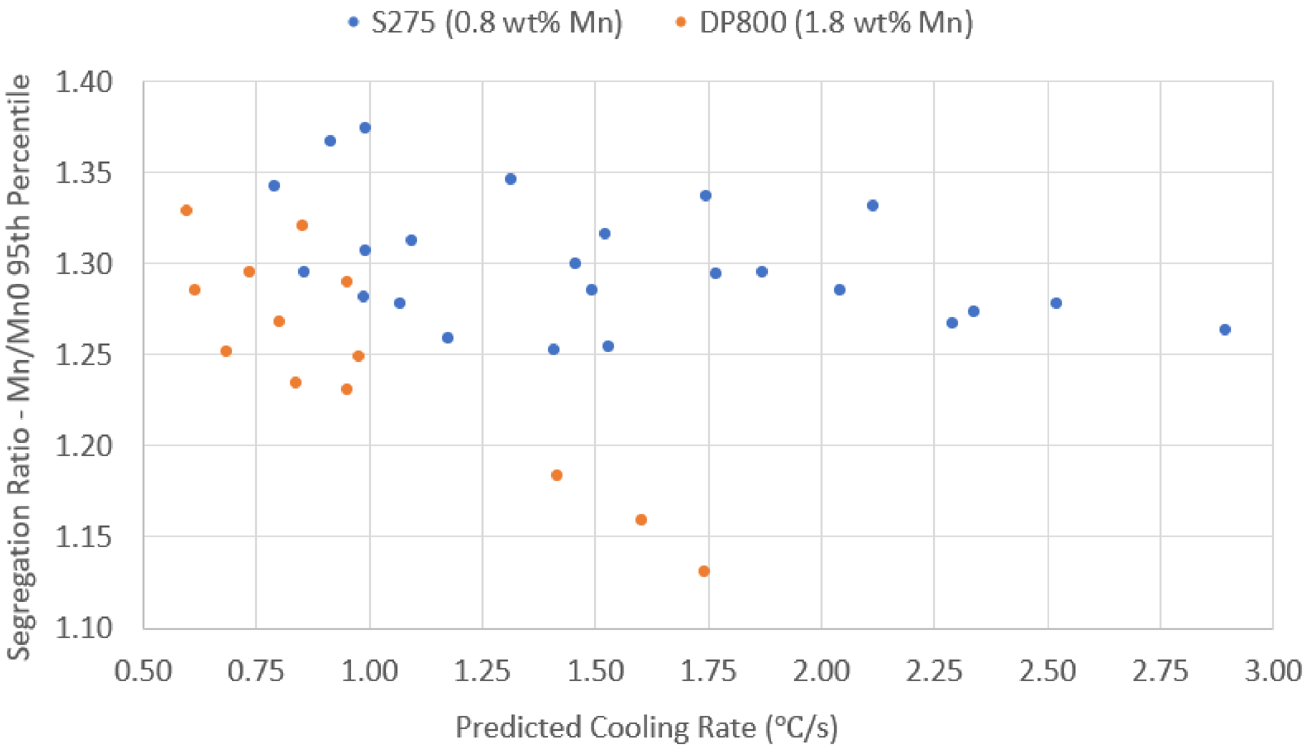




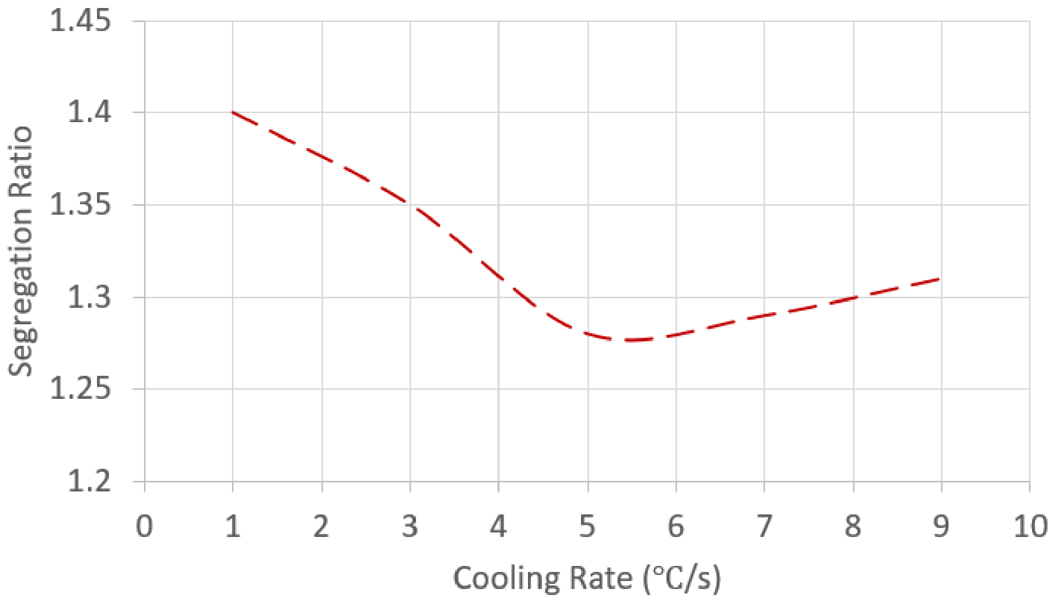
Segregation ratio against predicted cooling rates

- At slow cooling rates the segregation ratio for both steels is very similar. However, at higher cooling rates the SR for the two steels diverges. For DP800 a significant reduction in the SR can be seen at higher cooling rates, however for S275 a similar SR ratio is seen over the cooling rate range measured.

S275 vs DP800 analysis



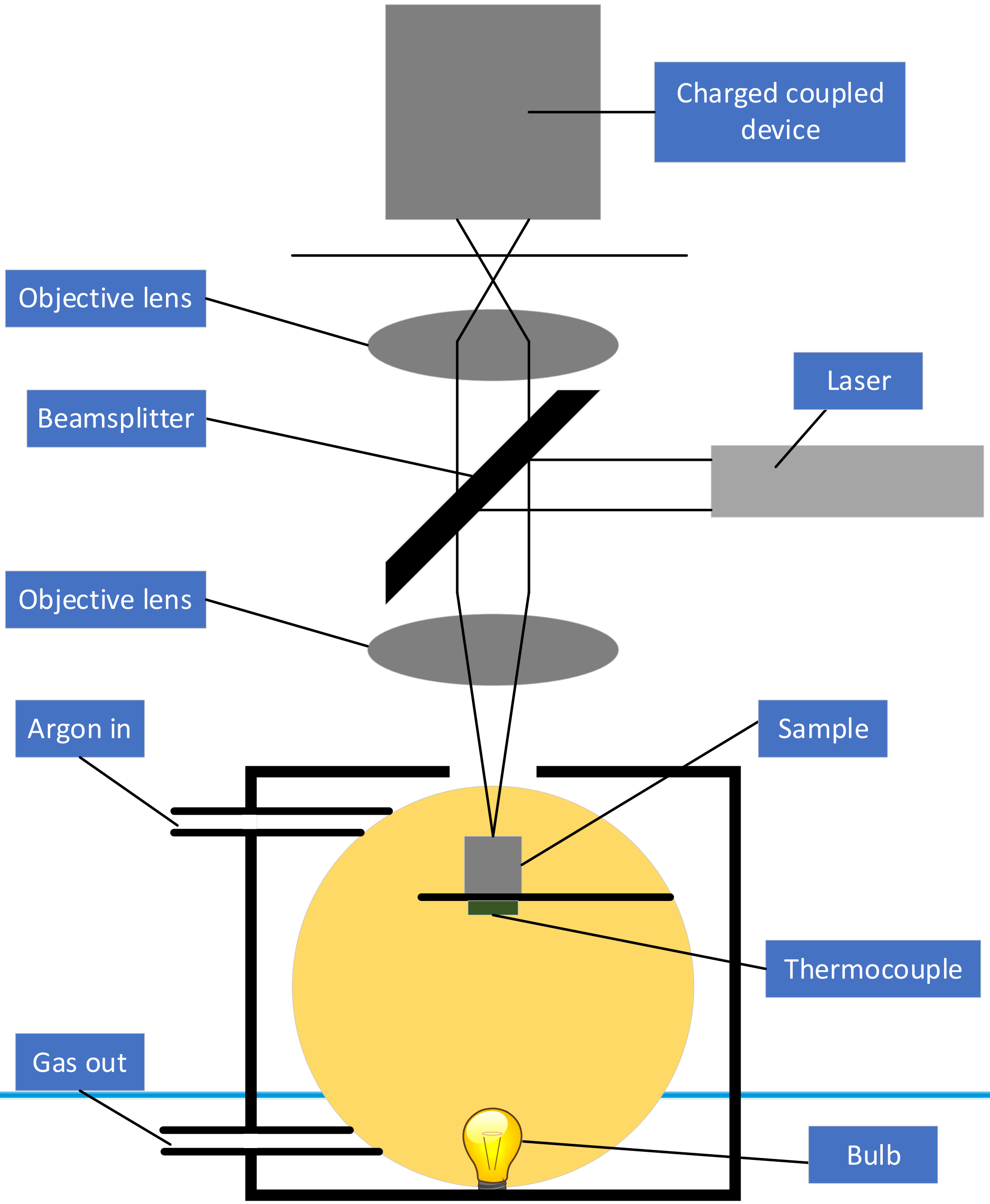
Predicting the segregation ratio at higher cooling rates

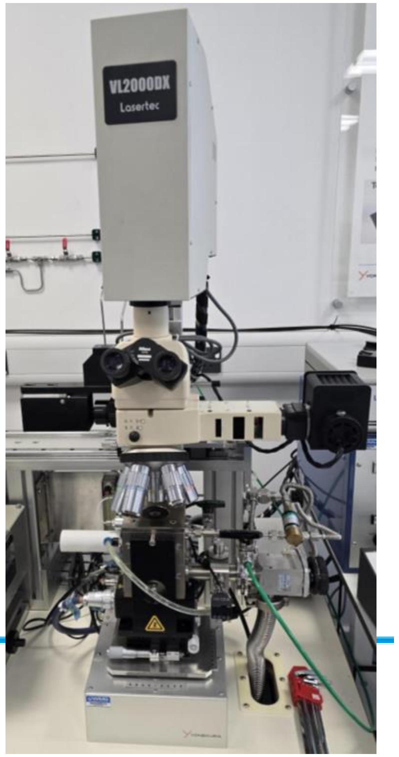


What can happen at higher cooling rates to the segregation ratio?

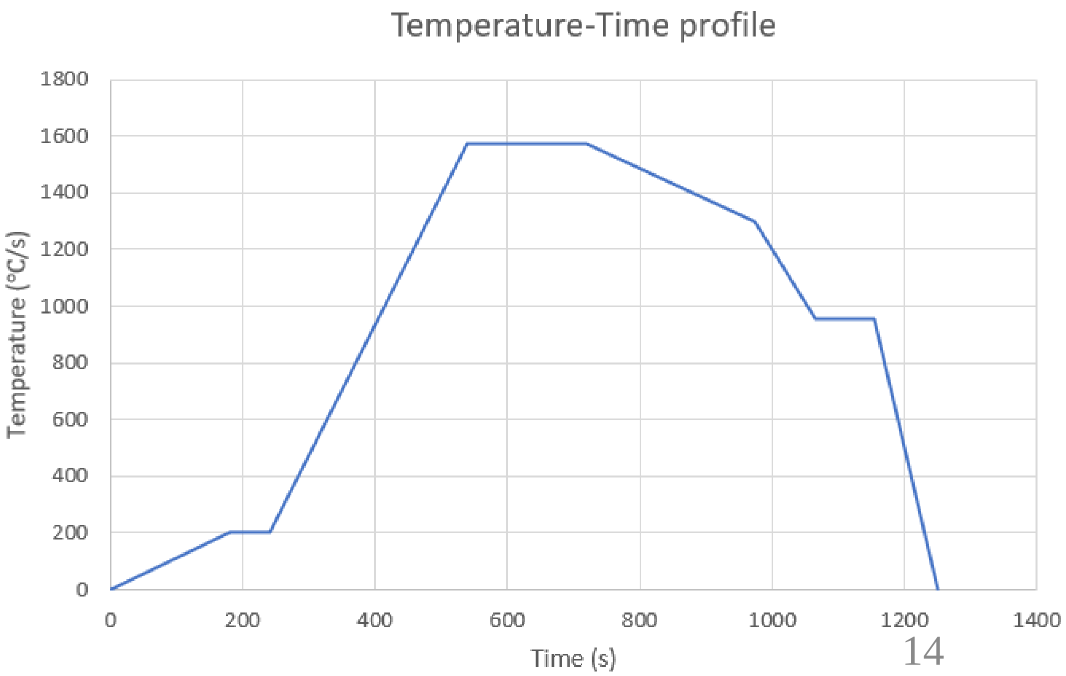
- The SR is affected by the equilibrium partition coefficient and then the back diffusion distance (SDAS) and diffusion time (cooling rate). As cooling rate initially increases the effect of the decrease in SDAS is most significant so the SR decreases. At higher cooling rates the decrease in SDAS become less therefore the hypothesis is that the reduced amount of time for back diffusion to occur will result in flat, or slightly increasing, SR.

CLSM - Taking into consideration cooling rates

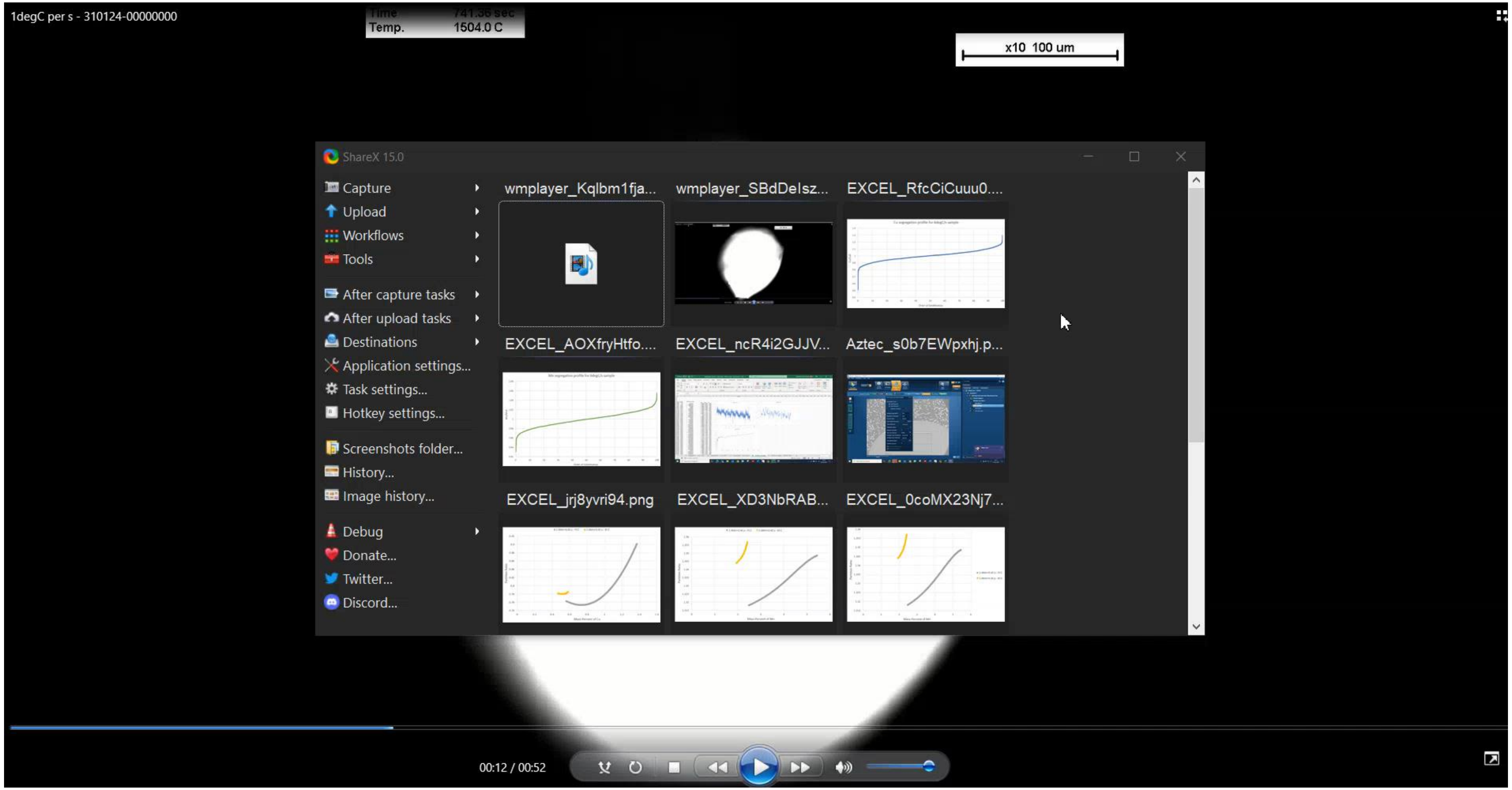




- A range of cooling rates can be achieved (0.5 ℃/s to 10 ℃/s (through solidification) using the Confocal Laser Scanning Microscope (CLSM). Higher controlled cooling rates can be targeted this way.
- The sample is heated by the radiation from the bulb (typical sample size of 5x5x5mm). The sample is observed through the microscope.



CLSM initial results for microsegregation and SDAS



Here the microstructure of the sample formed can be seen through solidification.

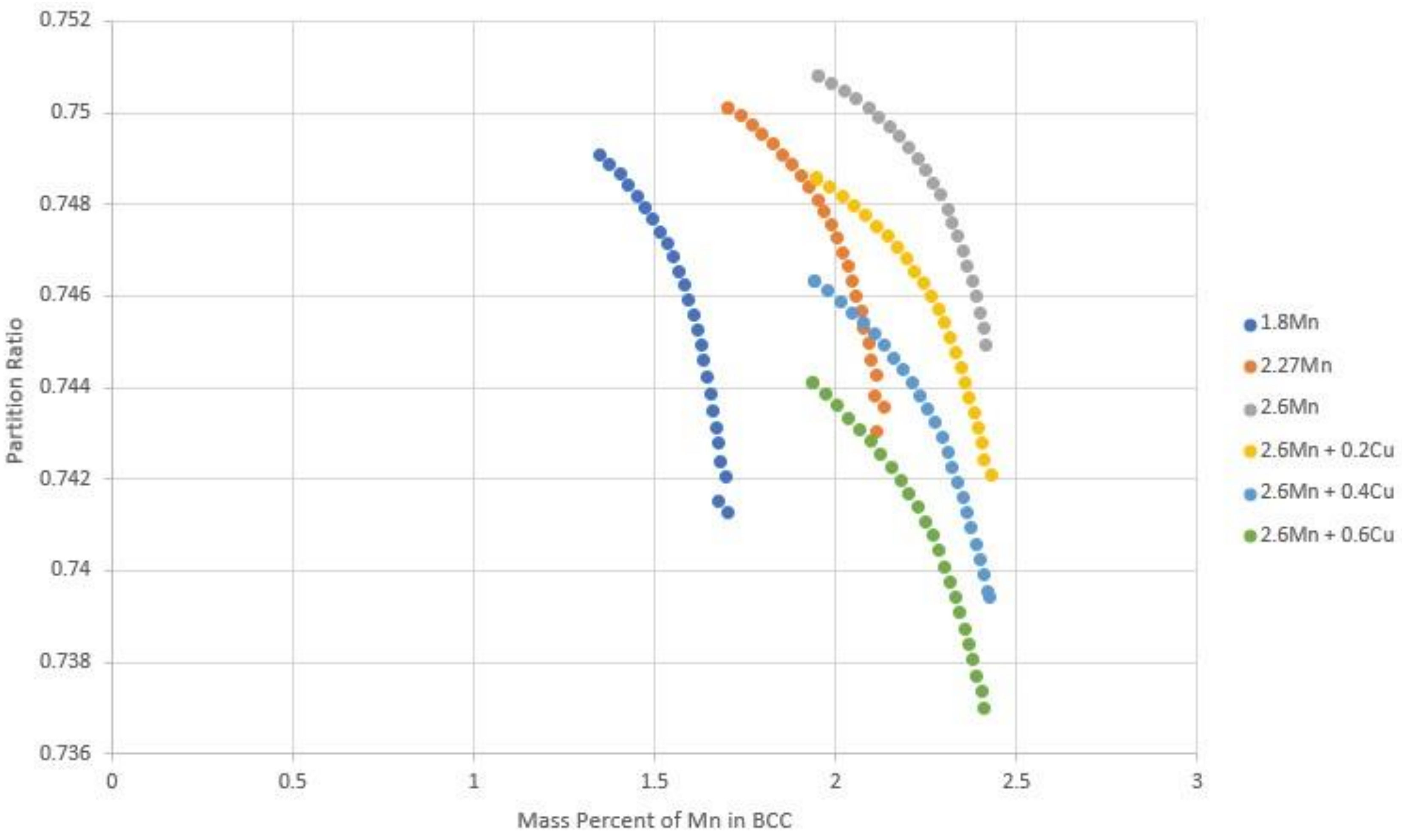
The secondary dendrite arm spacing can be seen to form and this can also be measured from the video output data.

Conclusions

- For the same cooling rates through solidification, it was seen there is a difference in SDAS for steels with different compositions.
- Segregation ratio for DP800 significantly reduced at the higher cooling rates compared to S275.
- Measured SDAS for DP800 was finer than S275 for all cooling rates. This indicates that the greater Mn content in the DP800 steel grade is contributing to the finer SDAS when compared to the S275 steel grade.
- Using the CLSM, a set-controlled cooling rate can be targeted through solidification and can also be used to measure SDAS.

Future work

- The effect of residual elements such as Cu is of great interest and how this will influence SDAS and SR.
- The partition ratio of Mn against the mass percent of Mn in BCC shows that the composition with Cu content from the graph shows a lower BCC partition ratio* than compared to changing Mn levels.
- This change is may indicate Cu is having a significant effect on the segregation behaviour and will be investigated experimentally.



* The partition ratio is equilibrium at solidification and does not take into account any back diffusion.

Thank you for Listening

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