The influence of cooling rate during solidification on segregation behaviour in low alloy steels

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February 2023

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Introduction

The ever increasing demand for reducing energy consumption in steel making means that using near-net shape casting is desirable. Different casting options are available, such as belt casting, thick/thin slab casting and strip casting, with associated differences in cooling rate and as-cast thickness. The cooling rates typically range from 0.6 °C/s for conventional thick slab continuous casting, to 500 °C/s for twin roll strip casting with as-cast thicknesses from around 1 mm to 250 mm [1].

It is important to assess how the different casting technologies affect the key metallurgical features that affect subsequent microstructure, and property, development. In addition the move to greater use of recycled scrap steel means that higher residual element contents will become common in steels and their influence needs to be considered.

This project aims to assess how segregation and as-cast microstructure (e.g. secondary dendrite arm spacing, SDAS) is impacted by moving to these low energy casting technologies, with a particular focus on residual elements. The initial stages of the work have focused on characterisation of as-cast DP800 and S275 steel to understand the effect of cooling rate on the SDAS and segregation behaviour of Mn, as the main alloying element present.

Approach, tests, results and discussion

Figure 1: The as-cast ingot from the wedge mould.

Using a COMSOL Multiphysics model the cooling rates through solidification were determined for a wedge mould (figure 1) that had been designed to provide cooling rates representative of thick slab, thin slab and belt casting (0.495 to 2.821 °C/s cooling rates obtained through thickness from the cast surface at different positions). DP800 and S275 grade steel compositions were chosen for initial characterisation. Micro-(X-ray fluorescence) XRF area mapping and scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDX) were used to construct arrays of line scans to characterise the microstructure and microsegregation levels for Mn.

Secondary dendrite arm spacing (SDAS) values from 53 to 115 µm are predicted at the different positions in the wedge mould casts (Figure 2). The equation for calculating SDAS is $SDAS = 84CR^{-0.45}$ where CR is the cooling rate [2]. It was found that as the cooling rate decreased, and SDAS increased, the segregation ratio increases for both S275 and DP800 (Figures 3 - 6). The segregation ratio is calculated from the Mn spatial distribution values as 95% percental value / average Mn content.

The segregation ratio reflects the partition value for the element between the solid and liquid and then the balance of time at temperature available to allow for back diffusion and the distance over which diffusion needs to take place, i.e. the SDAS (both of which give non-linear cooling rate sensitivities). From the results shown in Figures 3 - 6 there appears to be a greater effect of diffusion distance than back diffusion for the cooling rates examined as the segregation ratio decreases with the increase in cooling rate.

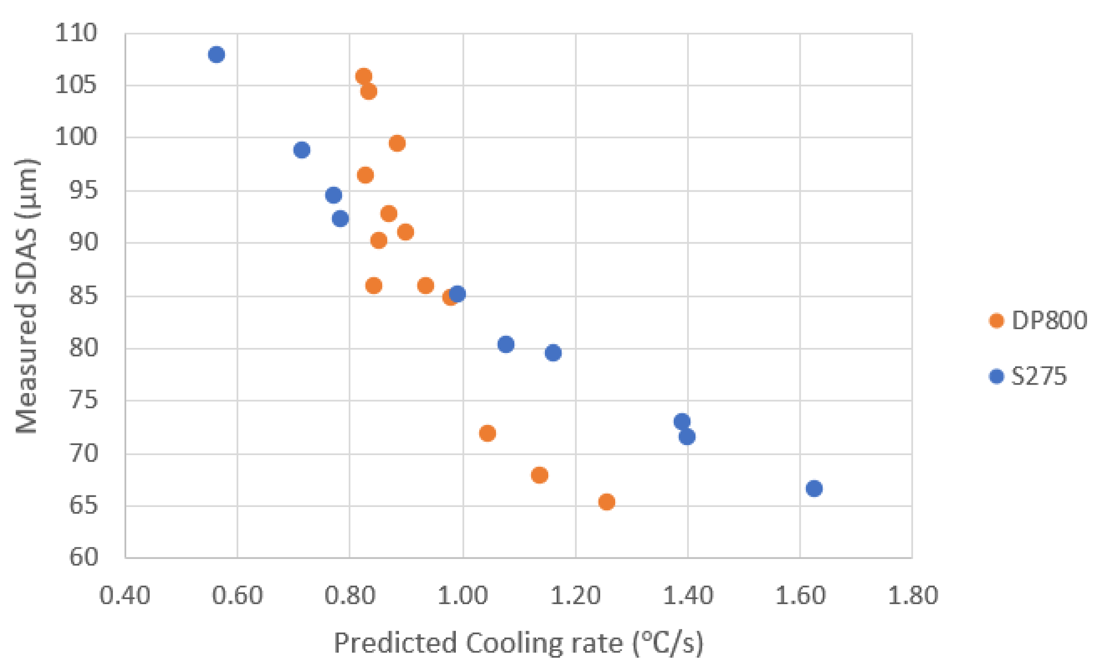

Figure 2 – showing the measured SDAS (µm) against predicted cooling rate (°C/s) (DP800 & S275)

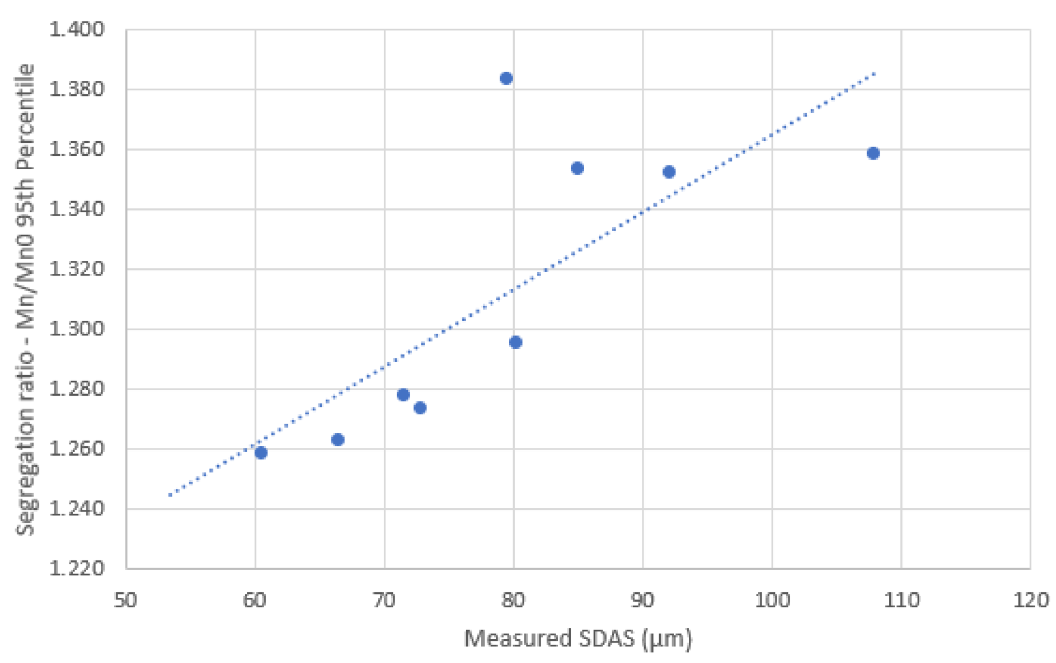

Figure 3 – showing the 95th percentile Mn/average Mn content (segregation ratio) for against measured SDAS (µm) → (S275)

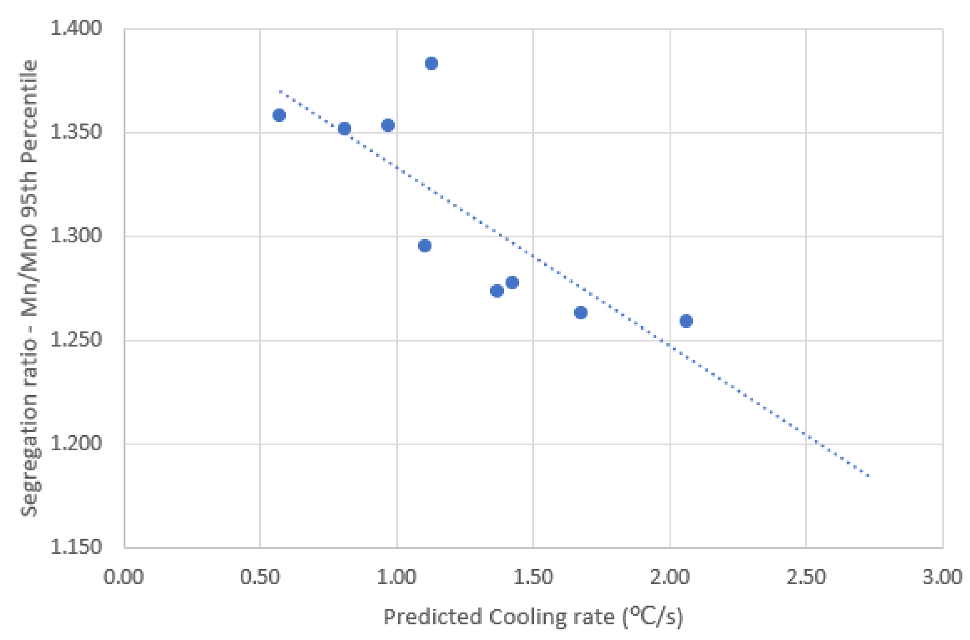

Figure 4 – showing the 95th percentile Mn/average Mn content (segregation ratio) against predicted cooling rate (°C/s) → (S275)

The DP800 steel grade showed a range of SDAS from 65 to 106 µm with segregation ratio from 1.13 to 1.33 (Figure 5-6). The S275 steel grade presents a range of SDAS from 61 to 108 µm with segregation ratio from 1.26 to 1.38 (Figure 3-4). This segregation ratio decrease with an increase in cooling rate for DP800 is in agreement with the S275 results.

The wedge mould for S275 showing solidification for different locations over a given period of time.

Scan QR code here to view solidification of the wedge mould.

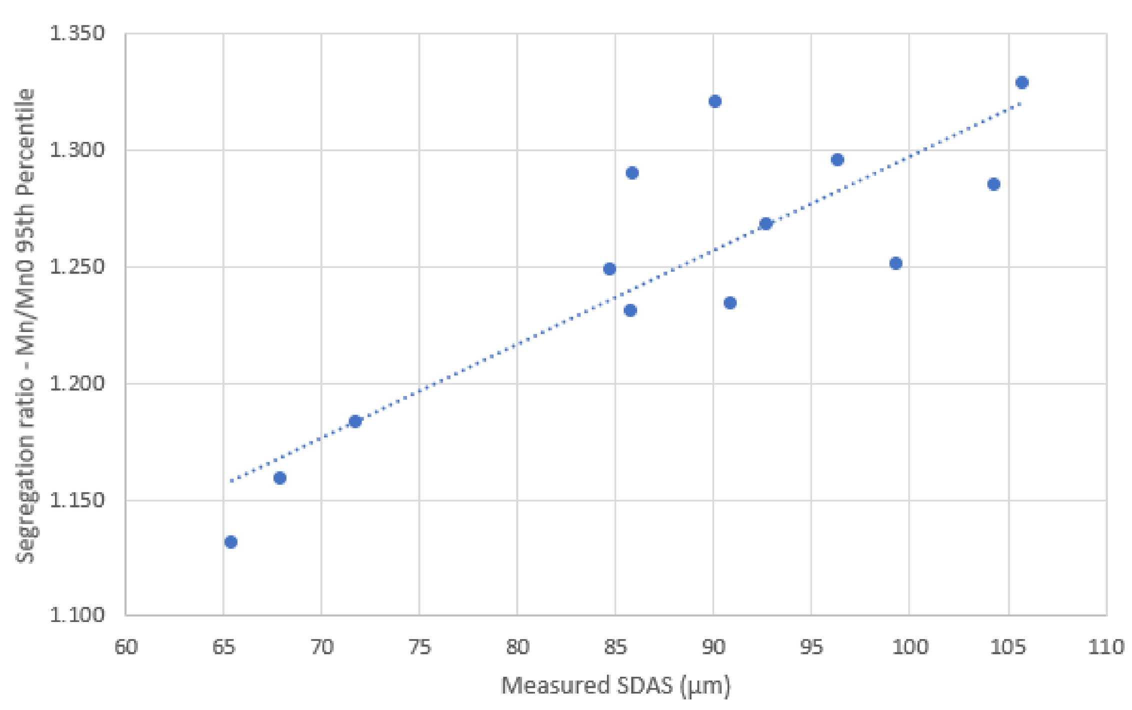

Figure 5 – showing the 95th percentile Mn/average Mn content (segregation ratio) against measured SDAS (µm) → (DP800)

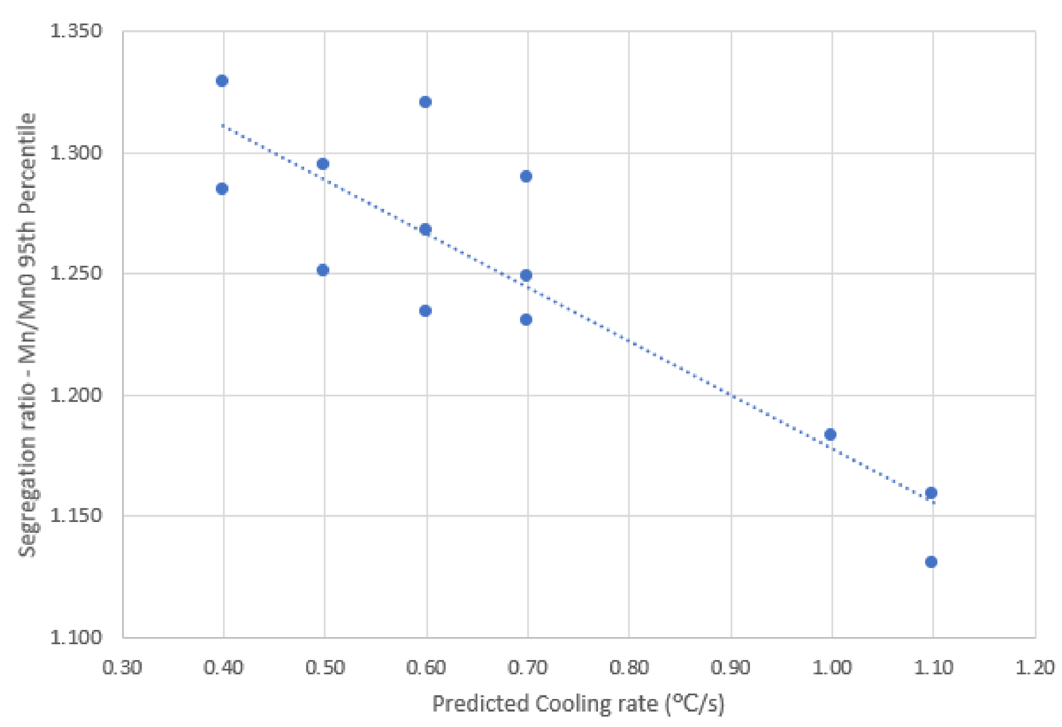

Figure 6 – showing the 95th percentile Mn/average Mn content (segregation ratio) against predicted cooling rate (°C/s) → (DP800)

Future work

The effect of cooling rate on the solidification structure (SDAS) and segregation behaviour when residual elements (particularly Cu, Sn and Ni) are present be investigated in the next stage of the work.

References

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

[2] Y. Zhu, C. Slater, S. Connolly, D. Farrugia and C. Davis. Ironmaking & Steelmaking 2021 Vol. 48 Issue 5 Pages 493-504

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