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Alloy Design for Impurity Tolerance

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BACKGROUND

The UK generated an estimated 11 million tonnes of steel scrap in 2018, and well over 70% of this was exported [1,2]. Maximising recycling rates by ramping up secondary steel production could help meet part of the growing steel demand. However, the quality of recycled steel is degraded due to the accumulation of impurity elements such as Cu, S and P which, through segregation, may embrittle steels, a problem limiting their use in high value applications. Impurity tolerance in alloy design refers to the process of developing alloys that can maintain desired properties even in the presence of unwanted elements. This can be achieved in many ways, and by changing the alloy chemistry, the objective is to investigate how alloy additions affect the segregation behaviour of these impurities. Focus has been placed on copper, which is the subject of this presentation and work to date.

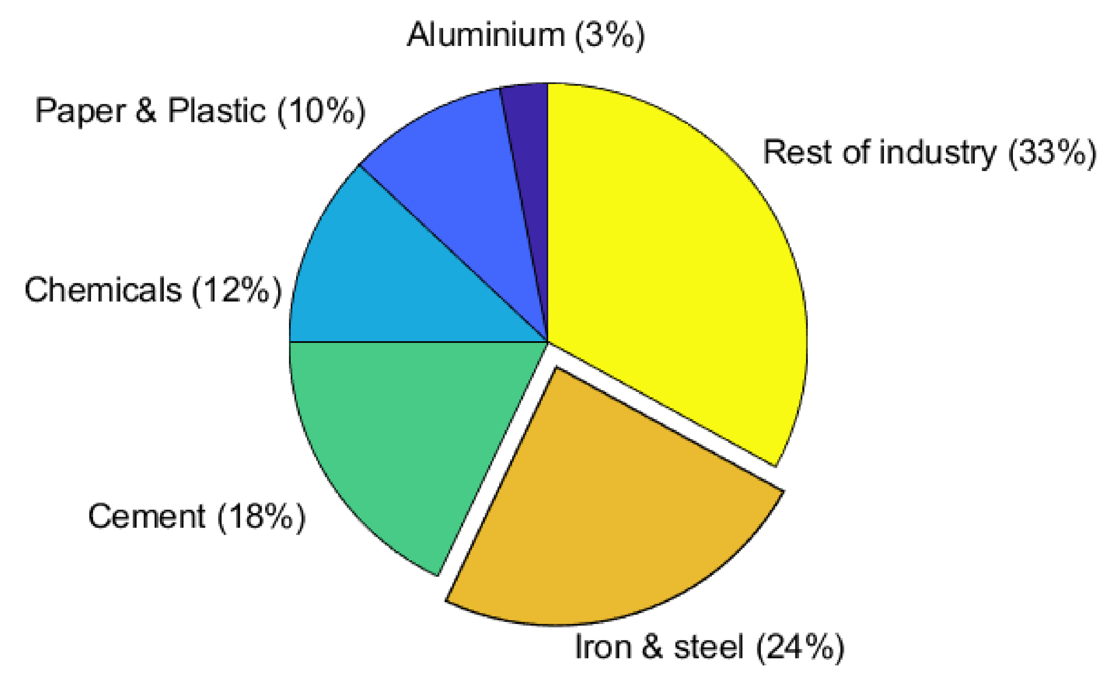

Fig 1. Estimated carbon dioxide emissions by material type in 2017 [3].

METHODS

Fabrication and Choice of Alloy Composition

Model steels of varying copper compositions (Table 1) have been fabricated in an electric arc melter at Imperial College London (Fig 2.).

Table 1. Composition selection for the high copper steel range. All compositions are in wt%.

Sample	Cu	C	Si	Mn	Fe
KAB22_R	1.2	0.2	0.1	1.0	97.5
KAB22_A	0.8	0.2	0.1	1.0	97.9
KAB22_B	0.4	0.2	0.1	1.0	98.3
KAB22_C	0.2	0.2	0.1	1.0	98.5

(a) (b)

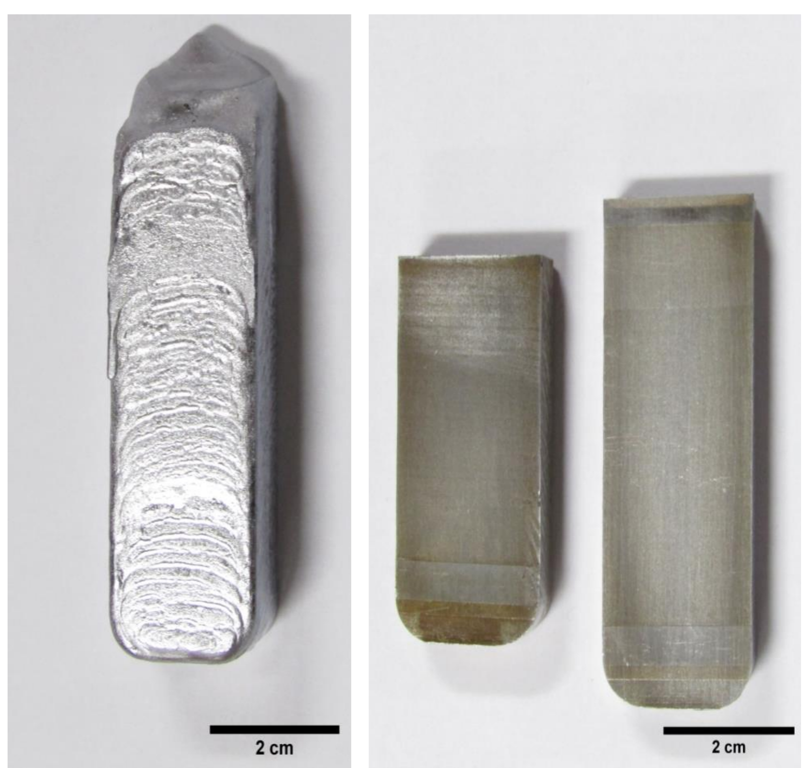

Fig 2. Images of cast KAB22_R alloy (a) cast ingot (b) EDM (Electrical Discharge Machining) sectioned ingot.

Characterisation

Characterisation by optical and scanning electron microscopy (SEM) is currently underway. Electron Dispersive X-ray Spectroscopy (EDX) and Atom Probe Tomography (APT) are to be used to characterise the distribution of S and P in the bulk, at defects and at grain boundaries.

(a) (b)

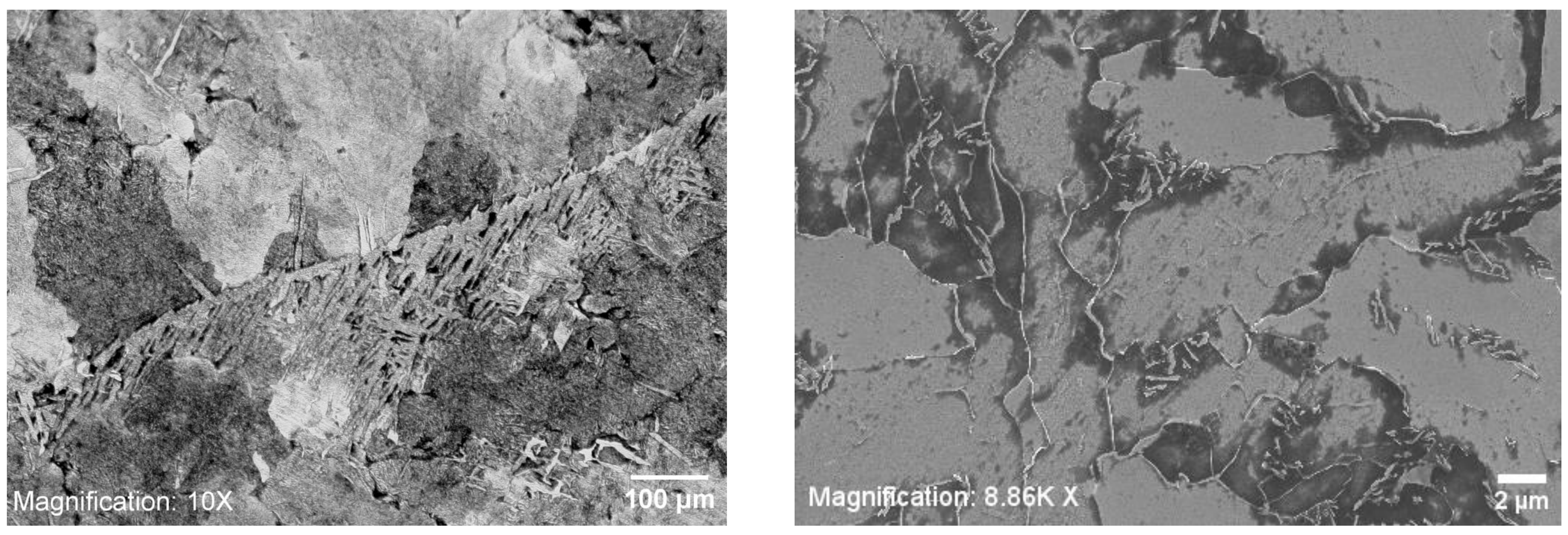

Fig 4. Images of cast KAB22_R alloy (a) 2% Nital etchant (b) Homogenised at 1300°C for 24 hours.

Thermodynamic modelling

Thermodynamic modelling through Thermo-Calc 2021b was used to predict phase diagrams, phases formed on solidification/growth of secondary phases and to calculate the segregation profiles in the primary phases. Using this information, estimated homogenisation and heat treatment times have been developed.

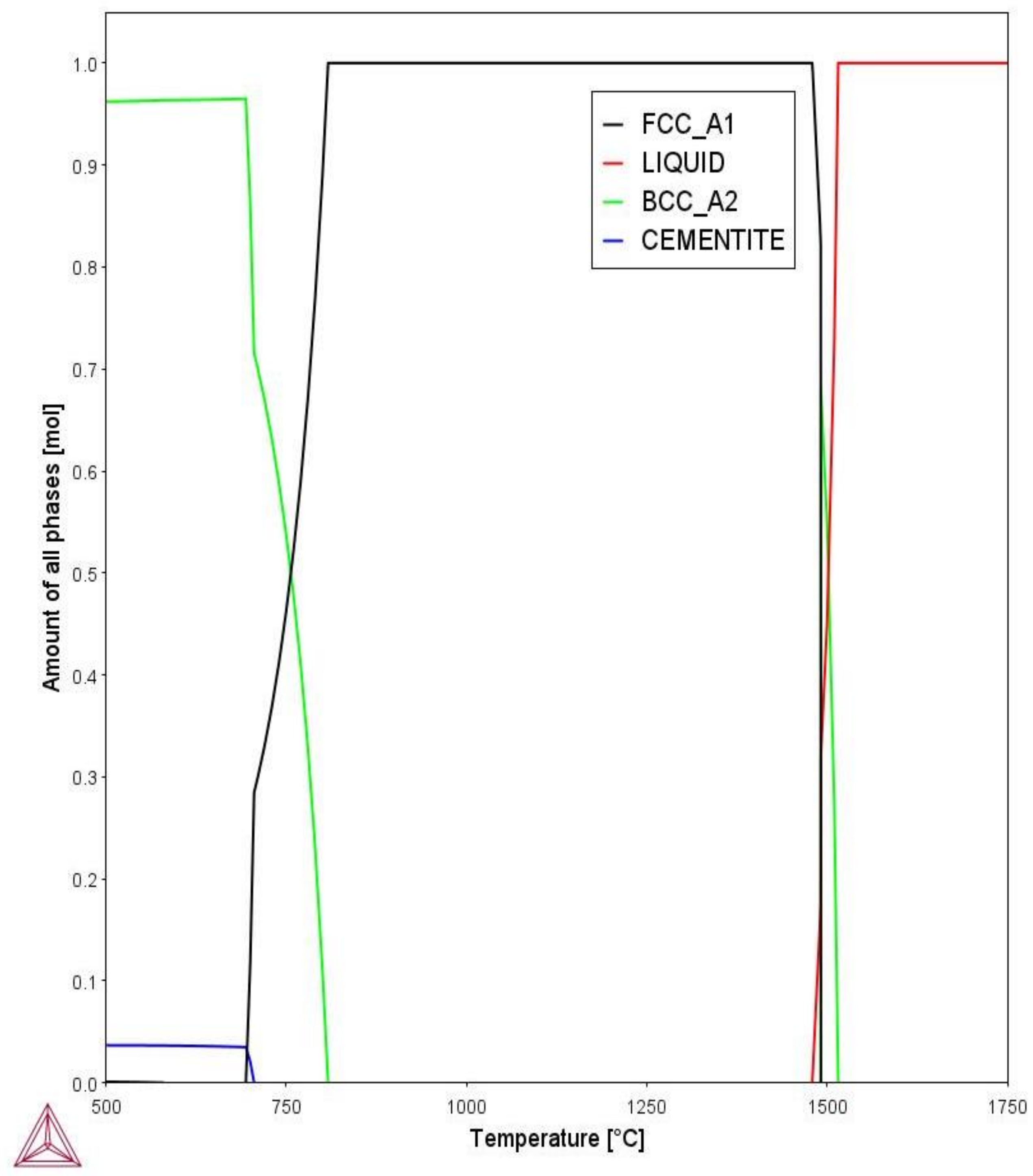

Fig 3. Simulation output showing how the amount of phases varies with temperature, a starting point for the development of heat treatment regimes.

NEXT STEPS

Complete the characterisation of samples with SEM & APT. Explore the evolution of copper clusters with heat treatment and quantify the extent of deterioration and improvement to tensile strength and impact toughness caused by Cu and alloying elements like Ni, Co and Si.

A similar assessment is to be carried out for impurity elements S and P.

REFERENCES

[1] Bureau of International Recycling, 'World-Steel-Recycling-in-Figures-2014-2018: Steel Scrap – a Raw Material for Steelmaking', Bureau of International Recycling, Brussels, Belgium, 2019. Accessed: Feb. 07, 2023. [Online]. Available: https://www.bdsv.org/fileadmin/user_upload/World-Steel-Recycling-in-Figures-2014-2018.pdf

[2] R. Hall, W. Zhang, and L. Zushu, 'Domestic Scrap Steel Recycling – Economic , Environmental and Social Opportunities - DEFRA Scrap Steel Report', University of Warwick, EV0490, 2021.

[3] M. Pooler, '"Green steel": The race to clean up one of the world's dirtiest industries', Financial Times, p. Feb 14, Feb. 15, 2021. Accessed: May 11, 2022. [Online]. Available: https://www.ft.com/content/46d4727c-761d-43ee-8084-ee46edba491a