

Solidification, microstructure and elemental partitioning in the FeMnNi medium entropy alloys

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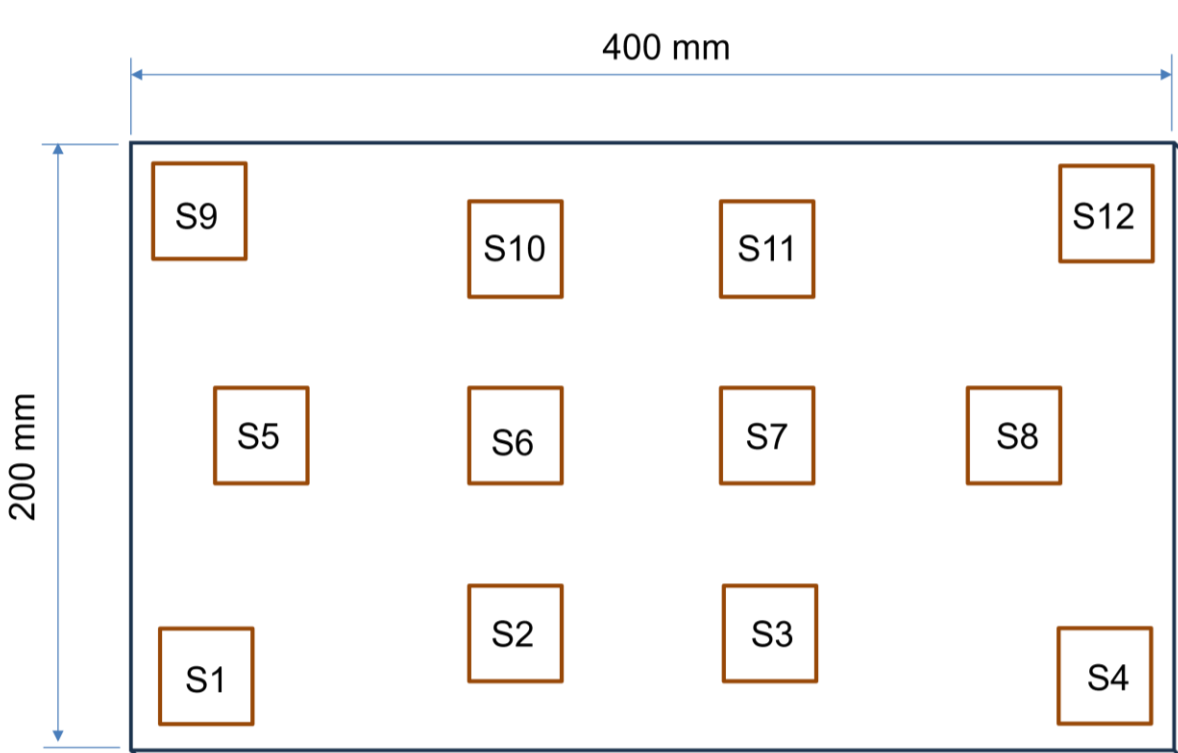
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INTRODUCTION & AIM

The ternary alloy FeMnNi [1], identified as MEA Cantor alloy system, exhibits a single phase (gamma γ) microstructure and FCC crystal unit within ~ 0 to 1490°C . There is a limited literature that explains the effect elemental behaviour in FeMnNi during solidification and microstructural evolution hence its effect on the metallurgical properties and response to processing. This investigation provides an ideal platform to explore first, the solidification behaviour of cast MEAs subsequently HEAs. Complexity arise as the number of elements is increased in the solid solution, recent research [2] investigated the effect of alloying on the microstructure of the as-cast HEA $(\text{FeMnNi})_{84}(\text{AlTi})_{16}$ showing evolution of double FCC matrix correlated with addition of Al and Ti to the FeMnNi system affecting the solidification range, insufficient diffusion with significant effect on its mechanical properties.

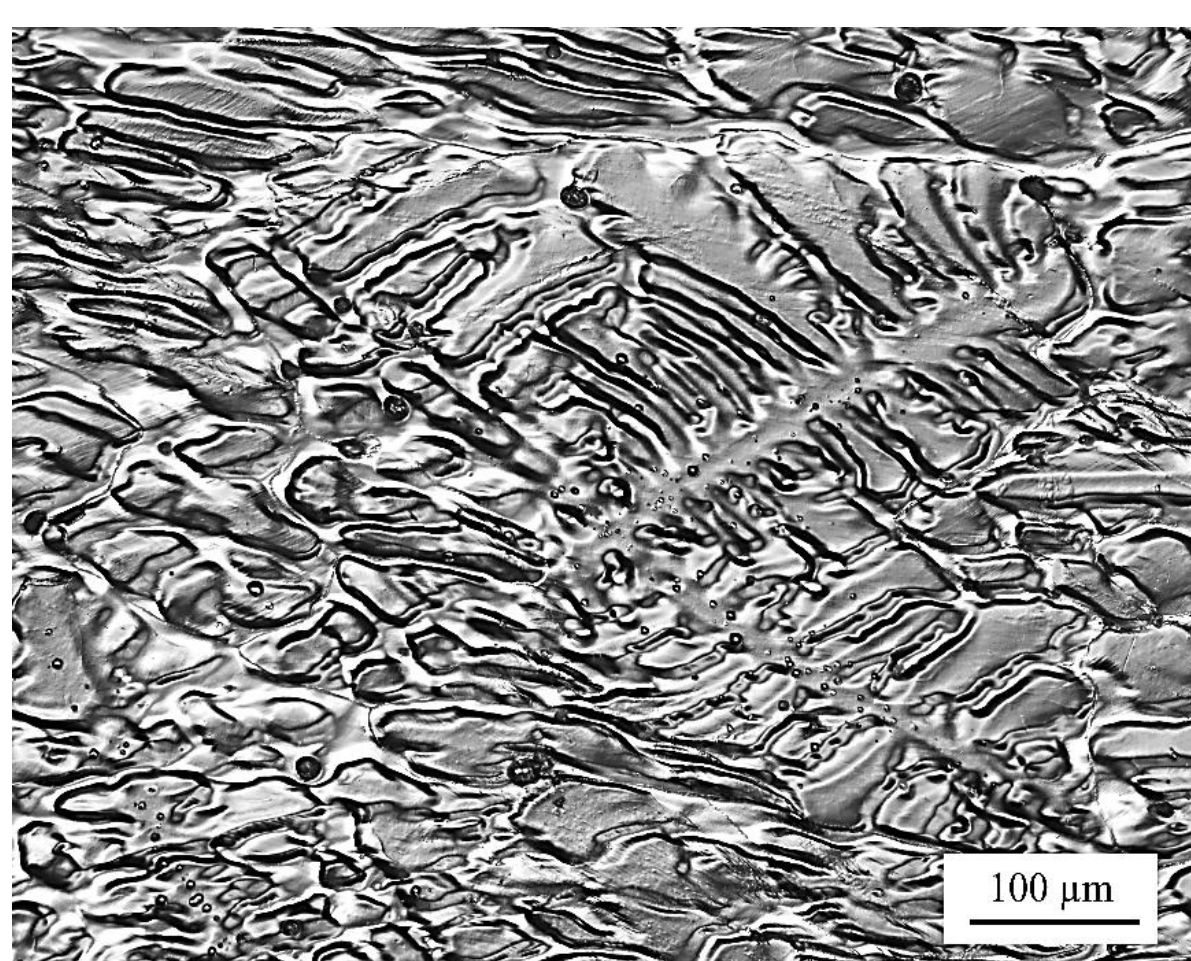
METHOD

In this work, melting of (FeMnNi ~ 33.33 wt% , $> 99.95\%$ purity) took place in a vacuumed-furnace ceramic crucible, and casting was done (at $\sim 1500^\circ\text{C}$) in a heat-resistant tool steel rectangular (400x200x10 mm) mould cavity. 12 representative samples (S1 – S12) the size of 10x10x10 mm were sectioned from the as-cast solidified slab, as seen in the schematic below for microstructure and elemental distribution examination.



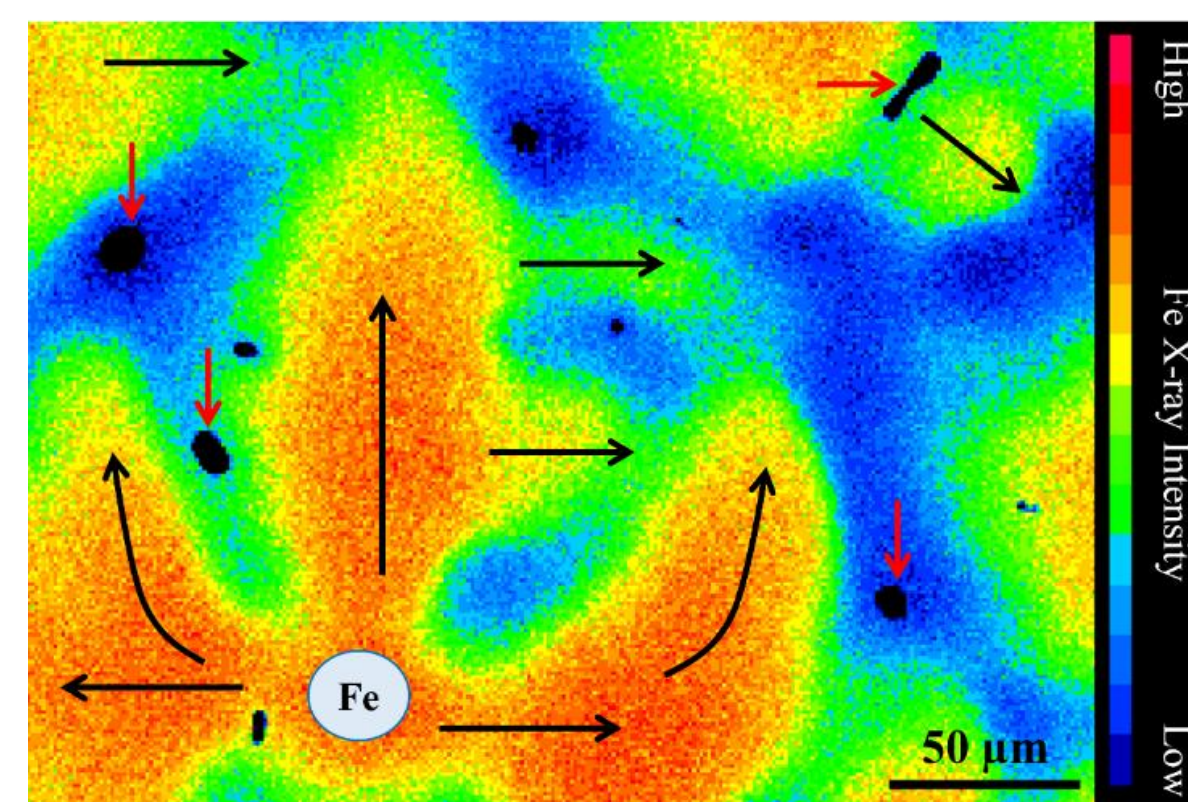
Dimensions of the 10 mm thick cast slab and the locations of the representative samples S1 -S12 considering the effect of mould geometry variations on the solidification rate and the microstructure at different locations

RESULTS & DISCUSSION



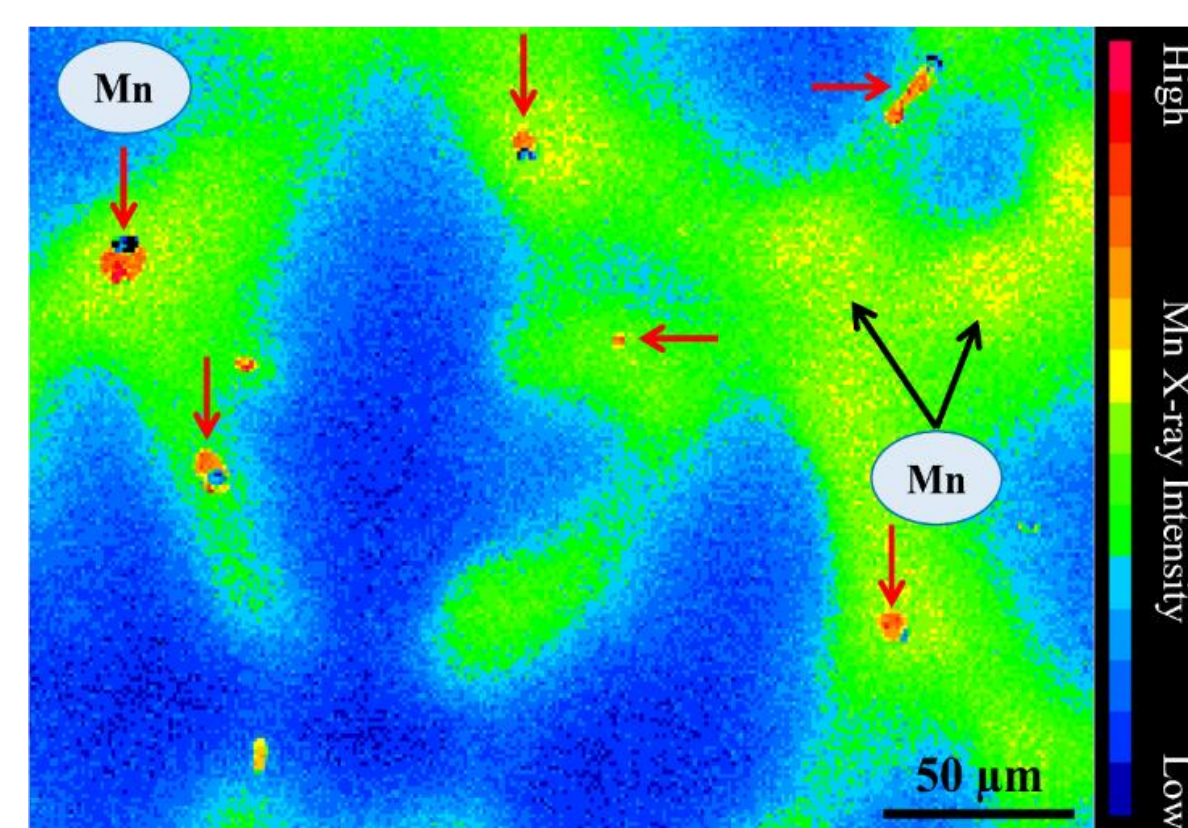
The Optical micrographs of all 12 samples revealed a predominantly large primary with finer secondary dendritic arms. Coarse and irregularly shaped grains with average size measured at (~ 630 microns) were also apparent throughout the cast microstructure.

The **EPMA** scans confirmed elemental segregation of Fe-rich (in the coarse dendrites) and Mn-enriched inter-dendritic regions, largely affected by the variations in the melting temperatures of the elements (Fe- 1538°C , Mn- 1246°C , Ni- 1455°C)



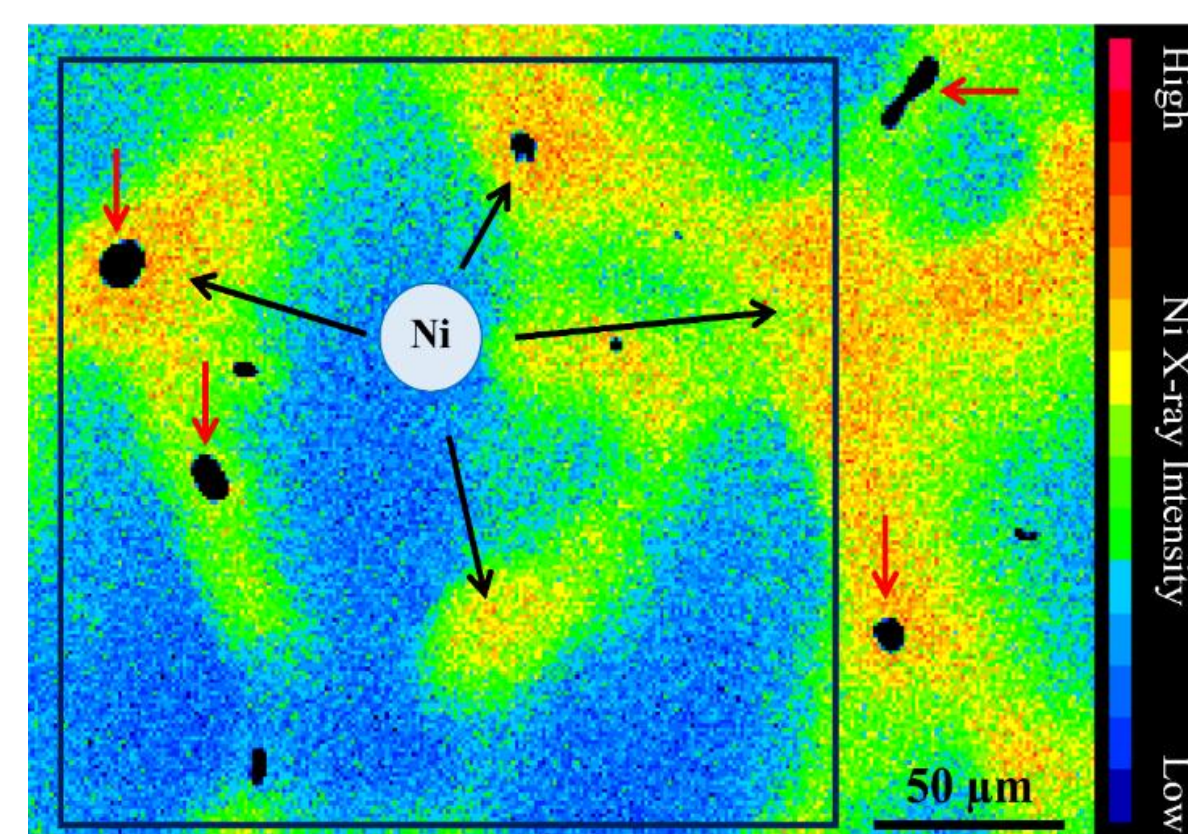
Fe solidification and distribution:

- Fe scans confirmed it is first to solidify in the Fe rich regions, mostly concentrated within the primary (coarse) arms of the dendrite



Mn solidification and distribution:

- Mn was depleted towards the outer (inter-dendritic) regions while concentrating in the secondary arms. Mn was also found concentrated around gas escape holes (with possible traces of Mn evaporating during casting at $\sim 1500^\circ\text{C}$)



Ni solidification and distribution:

- Ni is seen moderately distributed within the cast. A variation of $\sim 12\%$ between low Ni regions to high Ni regions was due to its lower melting point from Fe. Ni solidified at stages closer to the solidification of Mn.

Electron-prob micro-analysis (EPMA) scan of the cast FeMnNi

CONCLUSION

The effects of elements' physical properties and thermodynamic parameters including the atomic size, enthalpy of mixing (ΔH_{mix}) as well as the electron state on segregation behaviour during the solidification of the equiatomic FeMnNi composition is evident. The results highlight the potential of as-cast FeMnNi alloys as a model system for understanding metastability-driven deformation in MEAs hence HEAs, while pointing to their promise for structural applications requiring robust ductility and toughness, particularly under cryogenic conditions.

FUTURE WORK / REFERENCES

Recommended future studies on FeMnNi: 1) develop procedures for heat treatment, 2) measure its static and dynamic mechanical properties, 3) examine its behaviour during cold and hot rolling under selected variables, 4) design and assess properties of common joints FeMnNi weldments.

References: 1. G.V. Raynor and V.G. Rivlin, P.E.I.I.T.A., The Institute of Metals, London, (No. 4), 1988. 2. Konakoglou, K., et al., $(\text{FeMnNi})_{84}(\text{AlTi})_{16}$ High-Entropy Alloy: Correlation of Microstructure, Strengthening Mechanisms and Hardness at Various Conditions (As-Cast, Solution Treated, Aged). Metallography, Microstructure, and Analysis, 2022. 11(2): p. 309-326. 3. Jha, S.R., et al., Microstructure and mechanical property correlation in Silicon-doped equiatomic FeMnNi MEA: Experiments and simulation. Journal of Alloys and Compounds, 2023. 965.

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