NARUMI LAB.

Scinece in melting and solidification

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Exploring the mechanisms of microstructure evolution and crystal growth in non-equilibrium states

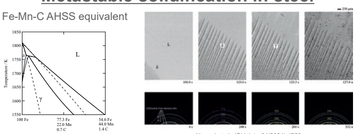
～ Real-time measurement of solidification and crystal growth phenomena using synchrotron X-ray imaging～

The processes of solidification and crystal growth from a melt are of critical importance in the production of metals and semiconductor materials, as they determine the resulting properties and functions of the materials. However, there are still many unexplained phenomena. From a scientific perspective, solidification and crystal growth phenomena, which represent a phase transition from the liquid phase to the solid phase, emerge from the dynamic behavior of atoms and manifest as a multi-scale phenomenon. In this regard, the dynamics of non-uniform fields of heat, mass, and momentum transfer are involved in a complex, competitive, and mutually interactive manner. A multitude of unresolved issues persist.

Notably, the inability to directly observe phenomena occurring in high-temperature melts that prevent visible light from passing through has been a significant impediment to research. However, recent advancements, such as the availability of high-bright X-rays at synchrotron radiation facilities like SPring-8, have enabled the observation of solidification and crystal growth in situ. In our laboratory, we are engaged in empirical studies of the dynamics of solidification and crystal growth that were previously unimaginable, as well as the construction and validation of physical models and simulations, with the goal of understanding new material processes based on observational facts.

Metastable solidification in steel

Fe-Mn-C AHSS equivalent

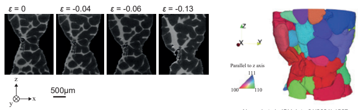


Narumi et al., ISIJ. Int., 64(2024) 1758.
Narumi et al., Tetsu-to-Hagane, 111(2025) 163.

In the supercooled melt of some iron alloys, such as steel, nucleation competition occurs due to the allotropic transformation of iron, and metastable solidification occurs in which metastable structures (δ) preferentially nucleate and gradually transform into stable structures (γ). The solidification structure formed by metastable solidification is finer and more uniform in chemical composition than equilibrium solidification and is attractive from the perspective of microstructure control.
To propose a new method for controlling solidification structures based on metastable solidification, we are conducting fundamental research to create a steady-state metastable solidification environment.

Semisolid mechanics

Compression of semisolid Al-Cu alloy (f_s =0.78)

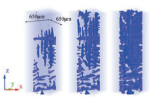


Narumi et al., ISIJ. Int., 61(2024) 1567.

Metallic materials can deform during solidification due to solidification shrinkage or external forces. When deformation occurs during the solidification process in a semisolid state where the solid and liquid phases are mixed, it will exhibit interesting mechanical behavior that cannot be described by solid or liquid mechanics, and this will lead to the formation of macroscale solidification defects such as cracks and voids, which will affect the properties and productivity of the material.
We aim to elucidate the deformation behavior and defect formation mechanism of semisolid alloys through direct observation and to construct a mechanical model.

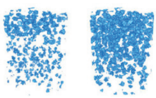
Observation of dendritic growth in alloys

CrMnFeCoNi(Cantor alloy)



Nakano, Narumi et al., Mater. Trans., 61(2020) 596.

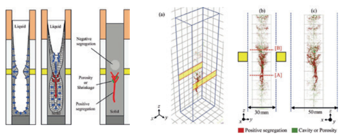
Al-Cu equiaxed dendrites



Narumi et al., J. Jpn. Inst. Light Metals, 70(2020) 339.

Dendrites in alloys are beautiful, like snowflakes, but while we are fascinated by their morphology, there is still a lack of scientific understanding of why they form this way and how they can be controlled. We are acquiring fundamental data through direct observation and quantitative evaluation of metal dendrite growth.

Nondestructive evaluation in cast ingots



Natsume, Narumi et al., ISIJ. Int., 63(2023) 1114.

We use synchrotron X-rays to non-destructively observe the internal structure of cast ingots of a size corresponding to the actual material. We quantitatively evaluate the distribution of chemical components and investigate the conditions under which segregation occurs, etc., and provide feedback on casting conditions.