Ternary V$_{ss}$-V$_3$Si-V$_5$SiB$_2$ eutectic formation in the V-Si-B system

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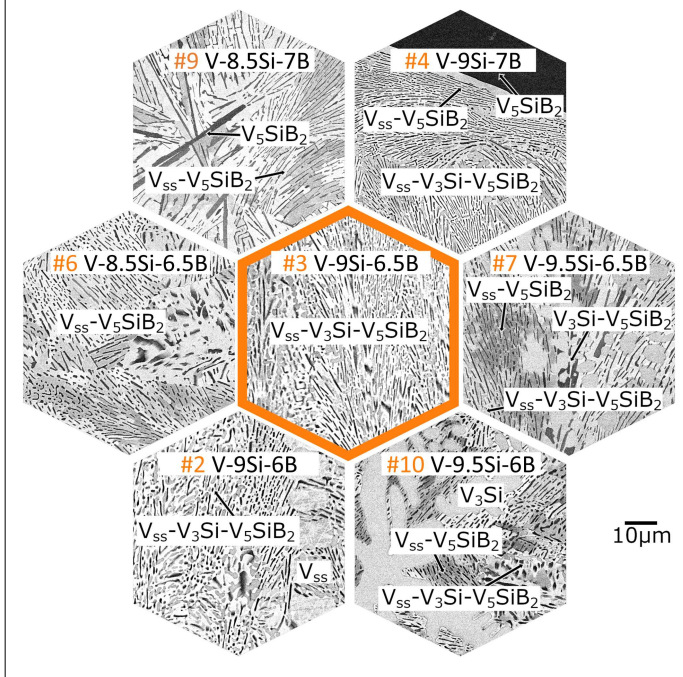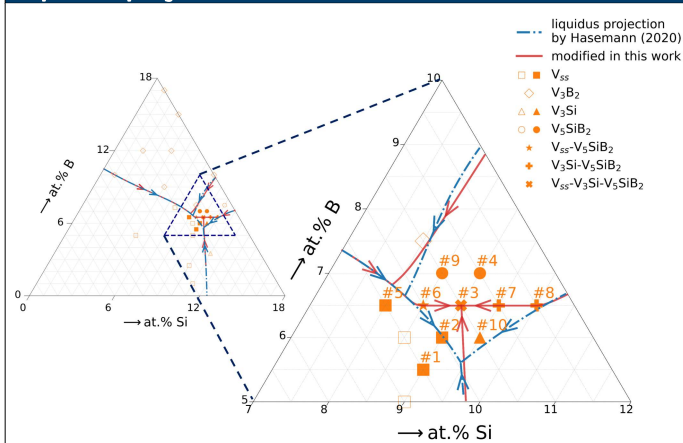[3]University Siegen, Institute of Materials Technology, Paul-Bonatz-Str. 9-11, 57076, Siegen, Germany
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Abstract

The solidification behavior close to the ternary V$_{ss}$-V$_3$Si-V$_5$SiB$_2$ eutectic reaction in the V-Si-B system has been experimentally investigated via arc-melting. According to the microstructure investigation, which is performed by scanning electron microscope (SEM) observations, energy-dispersive X-ray (EDS) and electron backscatter diffraction (EBSD) measurements and X-ray diffraction (XRD) analysis, the composition of the ternary eutectic reaction has been determined at V-9Si-6.5B (at.%). Its microstructures in two different sample sections with different cooling rates were further investigated and compared with the calculated result of the developed eutectic growth theory based on the Jackson-Hunt model [1] to reveal the competitive solidification behavior between the two-phase V$_{ss}$-V$_5$SiB$_2$ and three-phase V$_{ss}$-V$_3$Si-V$_5$SiB$_2$ eutectic growth. As a result, the liquidus projection around the ternary eutectic reaction was modified and the cross section of the ternary V$_{ss}$-V$_3$Si-V$_5$SiB$_2$ eutectic coupled zone along the monovariant V$_{ss}$-V$_5$SiB$_2$ and V$_3$Si-V$_5$SiB$_2$ reaction lines was schematically proposed.

Liquidus projection

legend:
- liquidus projection by Hasemann (2020)
- modified in this work
- □ ■ V$_{ss}$
- ◇ V$_3$B$_2$
- △ ▲ V$_3$Si
- □ ● V$_5$SiB$_2$
- ★ V$_{ss}$-V$_5$SiB$_2$
- ✦ V$_3$Si-V$_5$SiB$_2$
- ✳ V$_{ss}$-V$_3$Si-V$_5$SiB$_2$

#9 V-8.5Si-7B — V$_5$SiB$_2$, V$_{ss}$-V$_5$SiB$_2$, V$_{ss}$-V$_3$Si-V$_5$SiB$_2$
#4 V-9Si-7B — V$_5$SiB$_2$, V$_{ss}$-V$_5$SiB$_2$, V$_{ss}$-V$_3$Si-V$_5$SiB$_2$
#6 V-8.5Si-6.5B — V$_{ss}$-V$_5$SiB$_2$
#3 V-9Si-6.5B — V$_{ss}$-V$_5$SiB$_2$, V$_{ss}$-V$_3$Si-V$_5$SiB$_2$
#7 V-9.5Si-6.5B — V$_{ss}$-V$_5$SiB$_2$, V$_3$Si-V$_5$SiB$_2$, V$_{ss}$-V$_3$Si-V$_5$SiB$_2$
#2 V-9Si-6B — V$_{ss}$-V$_3$Si-V$_5$SiB$_2$, V$_{ss}$
#10 V-9.5Si-6B — V$_3$Si, V$_{ss}$-V$_5$SiB$_2$, V$_{ss}$-V$_3$Si-V$_5$SiB$_2$
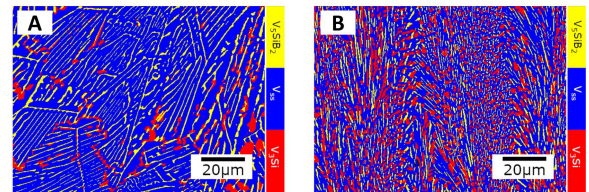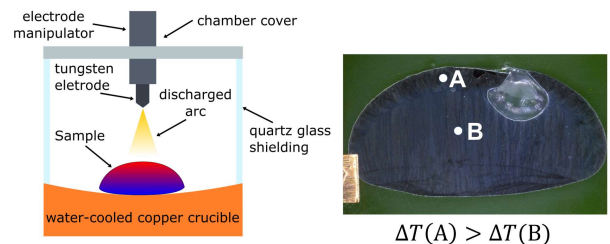10μm

Summary

- V-9Si-6.5B can be determined as the composition of the ternary V$_{ss}$-V$_3$Si-V$_5$SiB$_2$ eutectic reaction and the liquidus projection around the ternary eutectic reaction was modified, which can be used to design V-Si-B alloys close to the ternary eutectic reaction.
- The three-phase V$_{ss}$-V$_3$Si-V$_5$SiB$_2$ eutectic formation in alloy V-9Si-6.5B (#3) can be preferable at low undercoolings as compared to the two-phase V$_{ss}$-V$_5$SiB$_2$ eutectic formation, while the two-phase V$_{ss}$-V$_5$SiB$_2$ eutectic formation becomes the preference at high undercoolings.
- The three-phase V$_{ss}$-V$_3$Si-V$_5$SiB$_2$ eutectic coupled zone can be skewed towards the two-phase V$_3$Si-V$_5$SiB$_2$ reaction line and is therefore, another strong argument for the microstructure observation involving undercooling effects via arc-melting.

Competitive solidification behavior

Microstructures of different zones in alloy V-9Si-6.5B (#3)

electrode manipulator — chamber cover — tungsten eletrode — discharged arc — Sample — quartz glass shielding — water-cooled copper crucible

$\Delta T(A) > \Delta T(B)$

A — B — V$_5$SiB$_2$ / V$_{ss}$ / V$_3$Si — 20μm

Application of Jackson-Hunt theory

Model used for binary eutectic

θ_α θ_β — S_α S_β — β α β α — V$_{ss}$ V$_5$SiB$_2$

Model used for ternary eutectic

$\theta_{\alpha1}$ $\theta_{\beta1}$ $\theta_{\beta2}$ $\theta_{\gamma1}$ $\theta_{\gamma2}$ $\theta_{\alpha2}$ — $S_{\alpha1}$ S_β S_γ $S_{\alpha2}$ — β α1 β γ α2 γ — V$_{ss}$ V$_3$Si V$_5$SiB$_2$ V$_{ss}$

$K(V_{ss}$-V_3Si-$V_5SiB_2)$
$K(V_{ss}$-$V_5SiB_2)$
ΔT, average undercooling [K]
v, growth velocity [cm·s^{-1}]

$$\Delta T = K\sqrt{v}$$
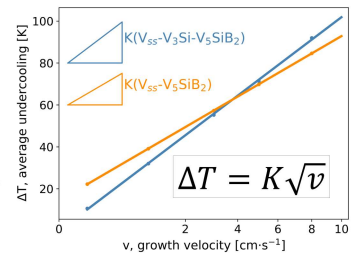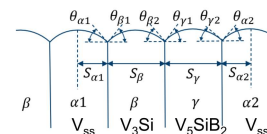
The cross section of the ternary eutectic coupled zone along V$_{ss}$-V$_5$SiB$_2$ and V$_3$Si-V$_5$SiB$_2$

$L \leftrightarrow V_3Si + V_5SiB_2$
$L \leftrightarrow V_{ss} + V_5SiB_2$
$L \leftrightarrow V_{ss} + V_3Si + V_5SiB_2$
T
B
A
$V_3Si - V_5SiB_2$ + $V_{ss} - V_3Si - V_5SiB_2$
$V_{ss} - V_5SiB_2$ + $V_{ss} - V_3Si - V_5SiB_2$
$V_{ss} - V_3Si - V_5SiB_2$
C_{Si} (C_B= constant)

$\Delta T(B)$ — $\Delta T(A)$ — B — A — T — C_{Si} (C_B= constant)

Acknowledgement

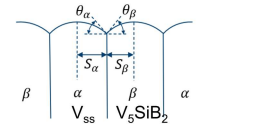Reference: [1] K.A. Jackson, J.D. Hunt, Transcations of the Metallurgical Society of Aime. 1988, 236, 363–376.