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Electron Microscopy of a Gas-Atomized NiSiV Powder

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Background incl. aims
Gas-atomization is a powder production technique involving rapid solidification of molten metal by high-pressure gas jets. Molten metal is poured through a nozzle into a chamber filled with inert gas where it is rapidly cooled and fragmented into fine, spherical particles by gas jets. The resulting particles are generally spherical with a high degree of uniformity in composition. There is a wide range of applications, from additive manufacturing and as feedstock to thermal spray coatings. In this study, a nickel silicide powder alloyed with vanadium has been investigated, with composition as stated in [1]. Nickel silicides are well-known for their resistance to high temperatures, corrosion, and oxidation, particularly in demanding environments such as in offshore applications. The powders are known to has high brittleness, but the incorporation of transition metals such as vanadium has been shown to improve the ductility. By using electron microscopy, both the surface and the internal structure can be investigated to gain a deeper understanding of the properties of the powder.

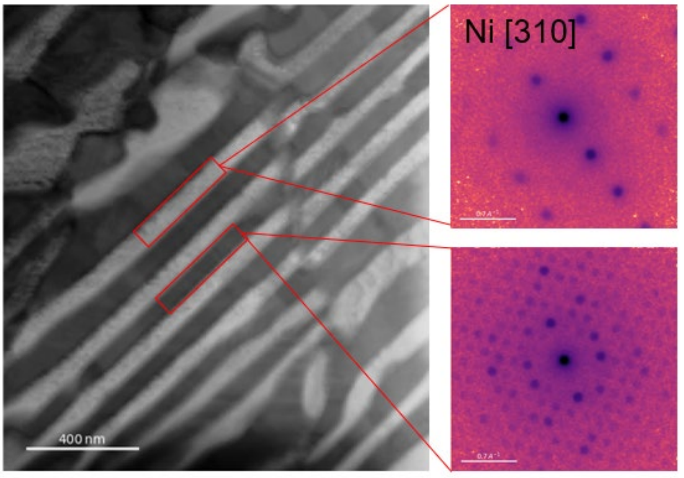
Methods
First, the particles surface and polished cross-sections were studied by scanning electron microscopy (SEM). A thin cross-section of a particle was prepared using a focused ion beam (FIB) and then investigated using transmission electron microscopy (TEM) imaging and energy-dispersive X-ray spectrometry (EDS) mapping. Scanning precession electron diffraction (SPED) maps were acquired to obtain high-resolution information on crystal phases and orientation relationships. The data was processed and investigated using the open-source Python libraries Hyperspy [2] and pyxem [3].

Results
SEM imaging reveals spherical particles with diameters from a few hundred microns down to a couple hundred nanometres. The particles are mainly uniform in shape but show signs of irregularities such as helmets and satellites. The surfaces are not smooth, but show signs of parallel stripes, revealing a lamellar dual-phase structure. The same stripes are visible in SEM images of the cross-sections. When looking at TEM bright field images, lamellae with a thickness of around 100 nm can be seen. EDS maps confirm that the lamellae are two distinct phases, alternating between vanadium-rich and silicon-rich, while the nickel is evenly distributed. Vanadium is very soluble in nickel at low quantities, and SPED was used to identify the vanadium-rich areas as the nickel fcc phase, in which vanadium has a high solubility. Equally, the diffraction patterns from the silicon-rich areas suggest a nickel silicide phase. While the crystal structure of nickel is very uniform along the stripes, the nickel silicide phase exhibits signs of misorientations and planar defects.

Conclusion
Gas-atomized nickel silicide powders alloyed with vanadium were studied using electron microscopy. SEM images reveal defects such as helmets and satellites, and structures both on the surface and on the cross-section. TEM methods such as EDS and SPED were used to study this further, and we were able to identify stripes with thicknesses of around 100 nm of alternating nickel solution with vanadium, and nickel silicide. Nickel is shown to have a

slightly increased lattice parameter with increasing amount of vanadium [4], which might make it a better lattice match with the nickel silicide phas and could possibly explain the improved ductility of the material when alloyed with vanadium. Further work includes obtaining a deeper understanding of the variations in the nickel silicide phase along the stripes and what effect this has on the properties, as well as the orientation relationships between the two phases.

Graphic:



Keywords:

TEM, SEM, SPED, Atomization, NiSiV

Reference:

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