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Microstructural Analysis of 3D-Printed Alloy 718.

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Three-dimensional printing (3DP), as an emerging additive manufacturing process in the last decade, is a promising technique for high-speed low-cost fabrication of complex parts compared with traditional methods. Although it is possible to 3D print complex alloys such as Ni-Cr-Fe alloys and stainless steels, the effect of this manufacturing process on the material microstructure remains a topic of research.

The microstructural complexity of Ni-Cr-Fe-Nb-Ti-Al alloy (Alloy 718) especially in terms of second phase precipitation is well-known and has been extensively characterized and studied in the past [1-3]. The main precipitates that have been identified in Alloy 718 are γ'' (Ni_3(Nb,Ti)), δ (Ni_3Nb), γ' (Ni_3(Al,Ti)), MC, $M_{23}C_6$, M_7C_3, M_6C and Laves. 3D-printed Alloy 718 microstructure is expected to be characterized by the presence of the same precipitates. However, the extent and distributions of these precipitates might be different from the conventionally-produced wrought alloy. These possible microstructural variations may affect macroscopic properties of the alloy such as elevated temperature resistance, creep resistance and strength. Therefore, a detailed microstructural characterization of the 3D printed Alloy 718 is needed in order to assess any differences from the conventionally-produced alloy.

In this study, a combination of field-emission gun (FEG) scanning electron microscopy (SEM), bright-field (BF) and dark-field (DF) transmission electron microscopy (TEM), and analytical electron microscopy (AEM) techniques have been used to study the microstructure developed in 3D-printed Alloy 718 with emphasis on the type and extent of precipitation.

The as-polished Alloy 718 was examined in a Zeiss MERLIN FEG-SEM with a GEMINI II column using both secondary electron (SE) and backscattered electron (BSE) modes. The microstructure was characterized by a layered and elongated grain structure (Fig. 1(a)) and by numerous subgrains (Fig. 1(b)). High resolution energy-selected backscattered electron analysis highlighted three different precipitate morphologies: coarse globular and plate-like intergranular brightly-imaging precipitates and fine acicular intragranular brightly-imaging precipitates. TEM analysis confirmed that the intragranular precipitates were γ" with a size of ~100 nm (Fig. 2). Discrete needle-like δ precipitates preferentially precipitated at high-angle grain boundaries. High resolution scanning transmission electron microscope (STEM) energy dispersive x-ray (EDX) microanalysis, using the FEI Titan G2 80-200 aberration corrected S/TEM equipped with super EDX, revealed marked micro-chemical variations in the fine precipitates. The disc-shaped γ" was composed of Ni, Nb and Ti, with a small amount of Al, and served as a nucleation site for subsequent precipitation of very fine γ" precipitates, which were enriched in Al (Fig. 4). These results will be discussed and compared with conventionally thermally-treated Alloy 718.

References:

[1] M.G. Burke *et al.* J. de Physique (1989) p. C8 395-400.
[2] Moukrane Dehmas *et al.* in Advances in Materials Science and Engineering (2011).
[3] D.F. Paulonis *et al.* in Trans. ASM (1969) p. 611.

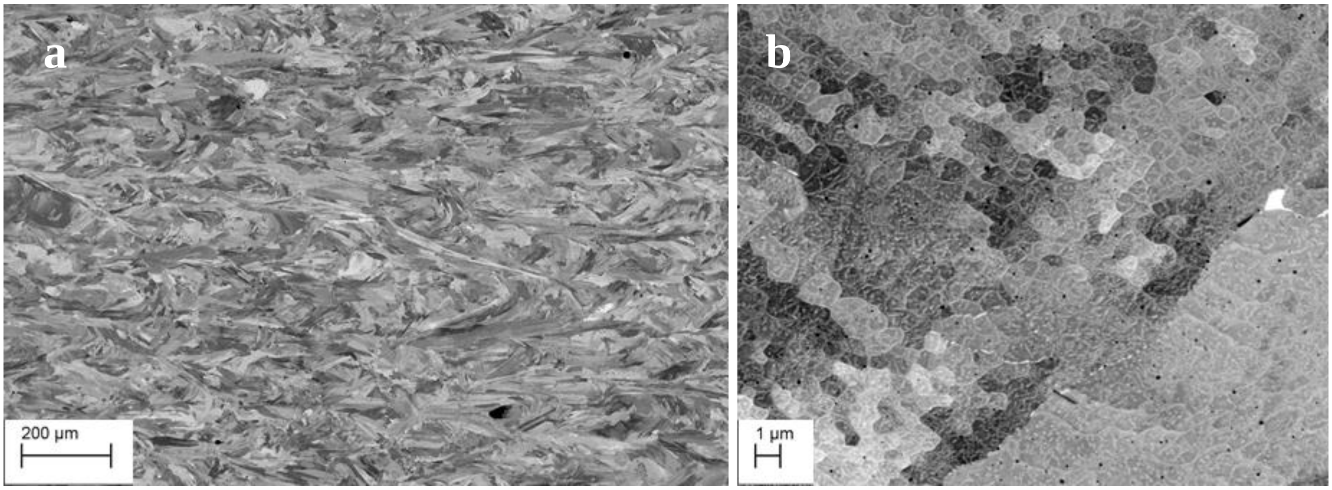

Fig. 1: (a,b) BSE images of the 3D-printed Alloy 718 microstructure and the subgrain structure.

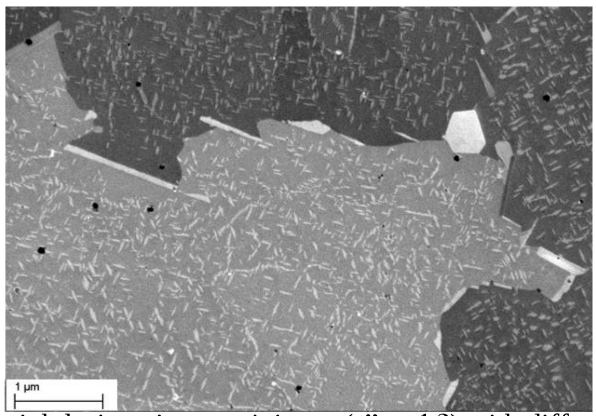

Fig. 2: BSE image showing the brightly-imaging precipitates (γ" and δ) with different morphologies.

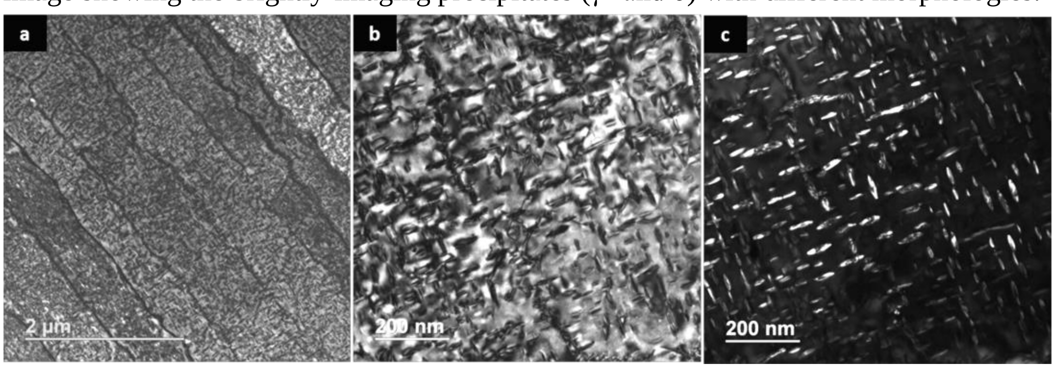

Fig. 3: TEM images of (a) the subgrain structure; (b) [001] BF and (c) DF images of the intragranular γ".

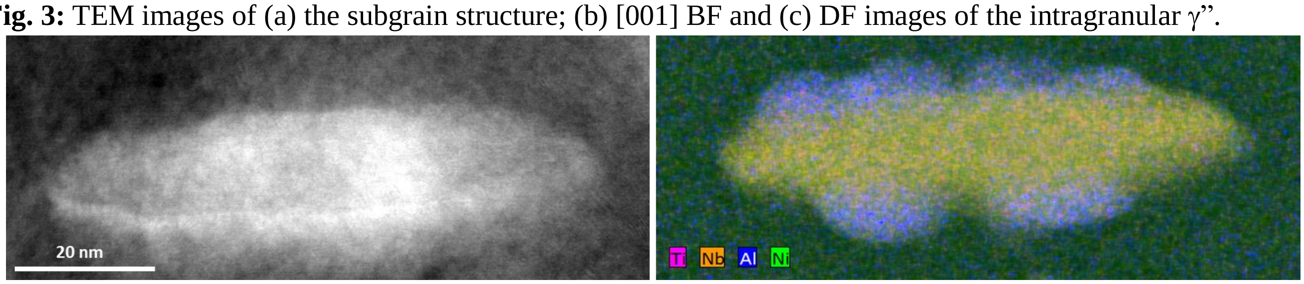

Fig. 4: HAADF STEM image and corresponding Titan "ChemiSTEM" SDD EDX spectrum images for Ti, Nb, Al, Ni of a coarse γ" precipitate with smaller discrete γ' precipitates that have nucleated at the γ"/matrix interface.