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Nanoscale Clusters and Heterogeneities in Engineering and Amorphous Alloys

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In this contribution, we review and demonstrate various methods by which we push back the existing characterization limits to better understand nanometric features in the smallest – arguably the most influential – features in both nanostructurally engineered materials and amorphous alloys. Engineering materials, relying on multi-phase strengthening, precipitation hardening, and cluster-strengthening, require an initial catalytic core for the formation of the desired precipitates or mesoscale phases. Amorphous alloys, though thought to have little structure, reveal heterogenous features on the nanoscale. There is thus a thrust in looking for these pre-precipitation clusters, nano-clouds, and heterogeneities in metallic glasses, which occur in a wide variety of materials research topics. For their analysis we take advantage of correlation techniques, between Atom Probe Tomography (APT), Transmission Electron Microscopy (TEM), and electron backscatter diffraction, some in combination with modeling and simulation and others utilizing our original atom probe cryo-transfer enabling developments [1].

We focus on the Fe–Cr alloy system to study detrimental effects such as phase decomposition and radiation damage, as it models ferritic steels relevant for the future fusion reactor. In the high-purity binary system decomposed into Fe-rich α and Cr-rich α’ upon annealing, we find intriguing details in the nanoscale α’ cluster and α/α’ interfacial chemistry [2]. We applied multiple analysis methods to determine the precipitate core composition, as their structurally coherent boundaries have often shown to be relatively broad compared to systems exhibiting classical nucleation and growth precipitation.

In SmCo-based high-temperature supermagnets, which are of paramount importance for the electromotive industry, we are able to determine the geometry, packing density and local chemistry between Zr-rich nano-platelets and Cu-rich cells, which prove to strongly influence the magnetic properties, such as coercivity [3]. Among these phases, even the finest clustering features may have a strong impact on the macroscopic magnetic properties. With respect to light metals, we show results on the room-temperature (‘natural’) aging of Al alloys for the aerospace industry and on precipitation in lean Mg alloys for biodegradable implants. Those light metals require specimens to remain at cryogenic temperatures from after their creation, from focused ion beam sharpening of the APT tips to transferring them to the atom probe and enable interrogating their arrested nanostructures [4,5].

Metallic glasses reveal they are not only amorphous or glassy in their atomic arrangements: FeB-based metallic glasses, albeit branded as having no mesoscale structure, reveal at the nanometer scale chemical heterogeneities after quenching, with further atomic reorganization upon thermal treatments. This suggests that even for these types of materials, cryo-transfer is increasingly essential to interrogate their as-solidified states at the highest spatial resolutions, when observed and quantified by combining TEM and APT methods.

These examples demonstrate the importance of nano-scale to near-atomic analyses not only to better understand the initial ‘gatherings’ of atoms (nano-clouds) within a structure, but to stress the continued need for pushing boundaries of the highest-resolution characterization methods, the correlation amongst them, and the deployment of cryo-vacuum transfer methods.

References:

[1] SSA Gerstl et al., Microsc. Microanal. **23** (2017), p. 612.
[2] S Küchler et al., Adv.Eng.Mat. (2021), p. 2100909.
[3] L Pierobon et al., Sci.Reports **10** (2020), p. 21209.
[4] S Pogatscher et al., Phys. Rev. Letters **112** (2014), p. 225701.
[5] M Cihova et al., Acta Mater. **158** (2018), p. 214.