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Electron Backscattered Diffraction Analysis of Electrodeposited Copper Coatings for Canada's Used Nuclear Fuel Containers

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Nuclear energy is known for its high stability and low carbon emission in electricity generation [1]; however, it poses a challenge for managing used nuclear fuel. In Canada, the Nuclear Waste Management Organization (NWMO) has proposed the concept of a Deep Geological Repository (DGR) for the permanent disposal of Canada's used nuclear fuel. Comprised of both natural and engineered barriers, the DGR will isolate and contain the used fuel from the environment. A major engineered component of the DGR design is the Used Fuel Container (UFC). The UFC is a vessel in which used fuel is packaged in prior to final underground emplacement. It consists of a carbon steel structural vessel with a 3 mm copper coating bonded to the external surface which acts as a corrosion barrier (Figure 1a). In the UFC manufacturing concept, the main components of the UFC (lower assembly and upper hemi-spherical head) will be pre-coated with copper prior to delivery at the Used Fuel Packaging Plant (UFPP). These components will be coated by the electrodeposition (ED) process. In the UFPP, used fuel is loaded into the lower assembly. The upper hemi-spherical head is then attached to the lower assembly by a closure welding operation which seals the UFC. The corrosion barrier is then completed by the application of a copper coating to the remaining narrow region about the closure weld zone by the cold spray process. In this study, microstructural characterization using Electron Backscattered Diffraction (EBSD) was performed on ED copper coatings produced by an acid electrolyte process to better understand the synthesis-structure-property relationships of this product.

EBSD was conducted using a Hitachi SU3500 scanning electron microscope equipped with an Oxford EBSD system to obtain the microstructural characteristics of ED Cu samples in the circumferential orientation (Figure 1a), including grain size, grain boundary character distribution, and crystallographic texture. The inverse pole figure (IPF) map of ED-Cu from acid electrolyte (Figure 1b) shows that there is a non-uniform distribution in grain size and notable evidence of twin boundaries, shown as parallel lines. The average grain size determined by the fitted ellipse diameter method is 2.9 μm, with the largest and smallest grains being 60.0 μm and 0.7 μm, respectively; however, approximately half of the total grains were identified to be smaller than 2 μm as shown in (Figure 1c). The band contrast map overlayed with coincidence site lattice (CSL) boundaries (Figure 1d) shows that $\Sigma 3$ twin boundaries are the most dominant grain boundaries (67%), followed by $\Sigma 9$ (4.8%), and $\Sigma 27$ (0.9%). In addition, 2.8% of the total grain boundary length is comprised of other low Σ (i.e. $\Sigma \leq 29$) boundaries. The pole figures (Figure 1e) indicate there is a weak (111) crystallographic texture.

The ED Cu coatings produced from acid electrolyte were found to have small grain sizes and a high proportion of special GBs. In general, all other things being equal, materials with smaller grain sizes are expected to exhibit more uniform corrosion behaviour across the surface [3]. Additionally, the special GBs such as $\Sigma 3$ twins and $\Sigma 3^n$ twin-related boundaries are expected to provide better corrosion resistance over random high angle boundaries (i.e., $\Sigma > 29$) due to their lower grain boundary energy.

From the microstructural standpoint, the present analysis shows that the ED Cu coatings possess desirable characteristics for corrosion resistance in support of the long term storage requirements.

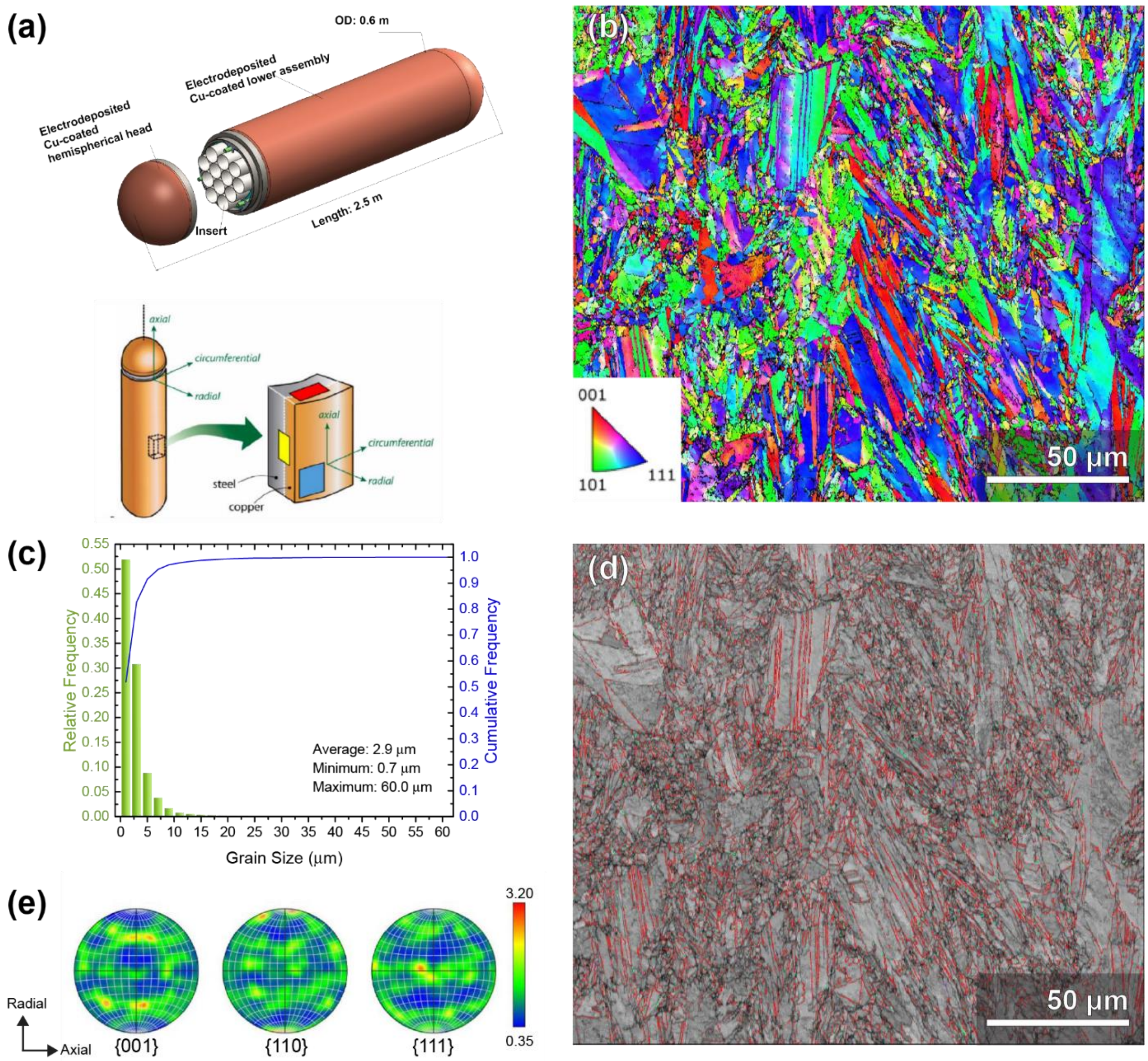

Figure 1. (a) Schematic diagram of the UFC and the coordinate system for characterization. (b-d) Microstructure characterizations of acid ED Cu in the circumferential direction. (b) Inverse pole figure map, (c) grain size distribution based on fitted ellipse diameter method, (d) CSL boundaries overlayed on band contrast map, (e) {001}, {110}, and {111} pole figure.

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