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# Characterization of Cadmium Whisker Growth Environment and Microstructure

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## Abstract

Widespread cadmium (Cd) whisker growth has recently been observed in a survey of Cd plated low-alloy steel fasteners used in high-reliability components. Whiskers were found on the fastener threads and head (both inside the socket and on the underside of the head); the most worn and debris covered areas exhibited the most dense whisker growth. The debris on the threads was identified through energy dispersive X-ray spectroscopy (EDS) as a combination of organic material and Cd oxide. Electron backscatter diffraction (EBSD) determined that the Cd whiskers were single crystal with a preferential $\bar{1}2\bar{1}0$ growth direction.

## Experimental

A survey of Cd plated field return parts, including nuts and fasteners, was conducted using optical microscopy (OM) to determine the prevalence and qualitative density of Cd whiskers. Fasteners were further evaluated with scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS) to determine the prevalence of whiskers, debris, and wear on the threads and around/inside the head.

Next, whiskers were harvested by rinsing the fasteners with alcohol on top of an aluminum stub. Alcohol removed the whiskers and other debris from the fastener and deposited them onto the stub upon drying. Rinsing was repeated on additional fasteners to generate a large quantity of whiskers and debris on the stub. These stubs were studied via SEM including EDS to determine the debris chemical makeup, and electron backscatter diffraction (EBSD) as well as x-ray diffraction (XRD) to determine the whisker growth direction.

## Background

Cd plating serves as a sacrificial anode for corrosion protection of steel parts (i.e. fasteners and nuts). A 1-2 µm chromate ($Cr_2O_7$) coating is often deposited on top of the Cd layer for further corrosion resistance. Like tin whiskers, Cd whiskers grow to relieve stress by physically transporting material away from the stress via a thin, long whisker, though there is no consensus on whisker formation and growth mechanisms (1-4). Sources of stress could include residual stress from the plating process, constraint from the chromate layer or other reaction products (precipitation or corrosion), damage and wear from service, etc. This study is motivated by the risk of foreign body contamination that Cd whiskers pose, while also seeking to understand the fundamental mechanisms behind Cd whisker formation and growth.

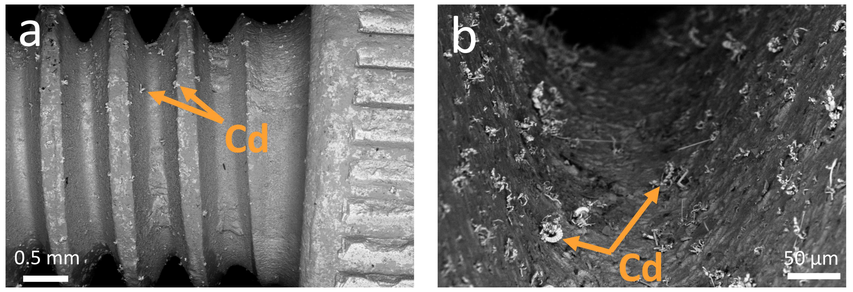



Figure 1: SEM backscatter images showing high Z Cd whiskers and non-whisker growths on (a) a worn fastener, and (b) a higher magnification between the fastener threads. Arrows indicate Cd features.

An optical microscopy survey of field return fasteners and nuts showed that Cd whiskers were found on 74% of the 32 batches surveyed. The batches which showed no whisker growth were new or almost new, showing very little wear and debris. The most dense whisker growth was observed on debris-covered, worn parts. Whiskers were found on fastener threads, inside and below the head. For nuts, whiskers were found only on the threads.

Figure 1 shows SEM characterization of a fastener with dense Cd whiskers and non-whisker features. Non-whisker features include pure Cd protrusions through the chromate top layer that are bulbous, curly, or agglomerates. It is common to see Cd whiskers growing out of agglomerates.

Figure 2 shows EDS results for the whiskers, non-whiskers and debris rinsed off of the fasteners with alcohol. Pure Cd and chromate ($Cr_2O_7$) are easily identifiable; other debris may include cadmium oxide, cadmium carbonate, or dirt, though the results are not conclusive. XRD on this material (not shown here) resulted in three unidentifiable peaks at low 2θ angles, suggesting that a mineral may be present other than a simple carbonate or oxide.

Thirty one whiskers were surveyed via EBSD. Figure 3 shows a typical whisker exhibiting sharp bends, or kinks, where the crystal direction remains the same but the whisker growth direction changes. All but one whisker was single crystal. A dominant $\bar{1}2\bar{1}0$ growth direction was observed in 25/31 whiskers, shown in Figures 3 and 4. In hexagonal materials like Cd, this corresponds to a close packed direction.

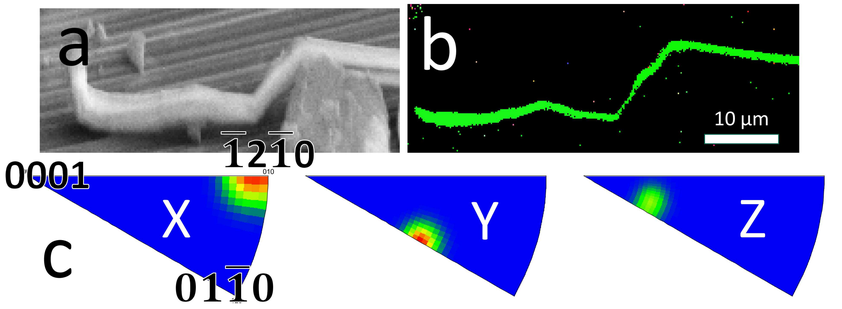



Figure 3: A typical Cd whisker exhibiting two kinks, but no change in crystal direction (a) the SEM image, (b) EBSD IPF-X map, and (c) inverse pole figures. Note that the IPF-X direction is horizontal.

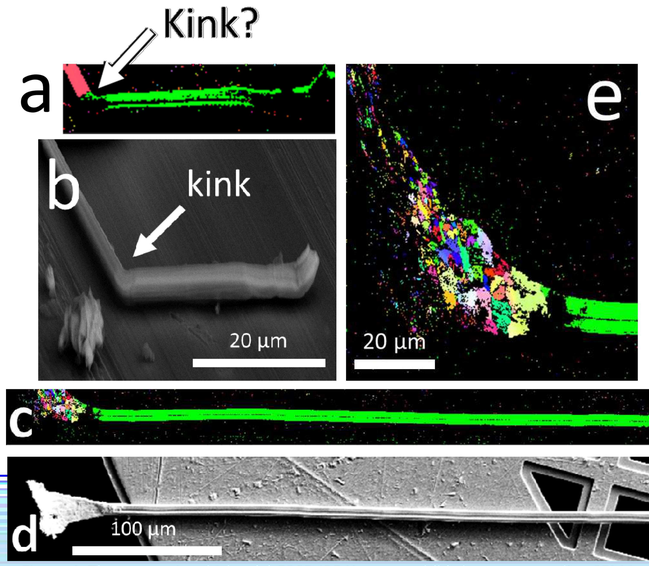
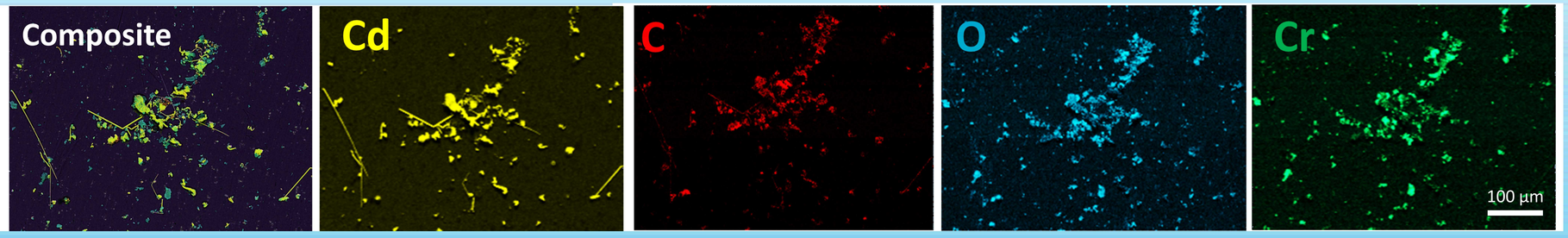



Figure 4: The two-grain whisker (a) EBSD IPF-X map, and (b) the corresponding SEM image. Als
map, (d) the corresponding SEM image, and (e) a higher resolution map of the Cd plating attac

Figure 4 presents two abnormal but interesting whiskers. Figure 4(a,b) shows the only whisker that was not single crystal. The two grains are joined at a 62° grain boundary. This two-grain structure has not been observed in previous studies of metal whiskers. The growth direction of both grains is $\bar{1}2\bar{1}0$.

Figure 4(c,d,e) shows a 600 µm long whisker which still has a piece of the cadmium plating attached; this whisker was removed from the fastener via tweezers. Notably, the whisker diameter is much larger than the plating grain size.

Figure 2: SEM EDS results of removed whiskers and debris, showing the composite and elemental maps for Cd, C, O, and Cr. Cr + O identifies pieces of the chromate layer. Pure Cd shows whiskers or non-whiskers. C may identify dirt or a carbonate.




## Conclusions

- Field return fasteners showed widespread Cd whisker growth. The whiskers are most prevalent in the most worn and debris covered areas.
- Cd whiskers were generally single cry
  direction.
- EDS showed the debris contained possible cadmium oxide or cadmium carbonate, plus organic material (dirt)
- To Do: Characterize the Cd plating to understand the microstructural conditions that are compatible with whisker growth
- To Do: Conduct whisker growth tests


### Citations

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