

# AGR-2 TRISO Layer Thickness Imaging Archive



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Nuclear Energy and Fuel Cycle Division

**AGR-2 TRISO LAYER THICKNESS IMAGING ARCHIVE**

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August 2024

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## ABSTRACT

As a part of fuel quality control characterization, optical microscopy images of particle cross sections near midplane were acquired at Oak Ridge National Laboratory (ORNL). These particles were produced by the Advanced Gas Reactor Fuel Development and Qualification (AGR) Program's AGR-2 irradiation campaign. These images may be of use for the development of image processing algorithms with the benchmark values measured at ORNL. This report provides those benchmark values, along with the raw images and data generated by the ORNL particle layer thickness analysis process.

## 1. INTRODUCTION

Optical microscopy of particle cross sections polished to near-midplane are used to measure the distribution of coating layer thicknesses within a given population of fuel particles. The general procedure is to (1) mount a large number (~hundreds) of particles in a materialographic mount, (2) polish to the approximate midplane while tracking the polish-down distance accurately using a height gauge, and (3) image each particle cross section individually using automated optical microscopy. Once images of all particles have been acquired, image segmentation is used to separate images of the central kernel and coating layers so that average individual layer thicknesses may be determined for each particle. If the particles are not polished to the exact midplane (as is generally the case because of the natural variation in particle size within a population), then the observed layer thicknesses in the plane of polish may be corrected to the nominal layer thicknesses at the midplane through a geometric polish-down correction which assumes spherical and concentric kernels and coating layers.

Full details of the implementation of this approach at Oak Ridge National Laboratory (ORNL) have been published [1]. This report provides layer thickness results, raw data, and the underlying images of the LEU-09 AGR-2 fuel acquired at ORNL.

## 2. BENCHMARK RESULTS FOR LEU-09

A total of 300 particles from LEU-09 were successfully polished, imaged, and processed for determination of layer thicknesses. Kernel radii were also measured for these particles, and that data are reported herein; however, the impact of uncertainties in the polish-down correction is the greatest for the kernel for two reasons. First, the magnitude of the polish-down correction is the greatest near the center of the particle and thus has the greatest impact on the kernel. Second, errors in the polish-down correction are partially offsetting for layers in which the polish-down correction is applied to both the inner and outer layer boundaries. In the case of the kernel, there is only a single boundary, so this offsetting of errors is not realized. In general, shadow imaging of bare kernels is the more accurate method to use for measurement of kernel diameter.

It should also be noted that although 300 particles were successfully processed, the results from each particle were not always included for each layer. Operators reviewed images to identify cases in which the automated image segmentation algorithm failed to adequately segment the layer boundary. This occurs most commonly as a result of polishing damage in the relatively fragile kernel/buffer interface, so the data obtained for those two regions were discarded. In this dataset, data for the kernel and buffer layer were rejected for 46 particles, leaving 254 particles with results for all layers.

The mean kernel radius measured for LEU-09 was 209.8  $\mu\text{m}$  with a standard deviation of 6.2  $\mu\text{m}$ . The mean buffer layer thickness measured was 105.2  $\mu\text{m}$  with a standard deviation of 10.0  $\mu\text{m}$ . The mean inner pyrolytic carbon (IPyC) layer thickness measured was 40.9  $\mu\text{m}$  with a standard deviation of 2.6  $\mu\text{m}$ .

The mean silicon carbide (SiC) layer thickness measured was 34.4  $\mu\text{m}$  with a standard deviation of 1.1  $\mu\text{m}$ . Finally, the mean outer pyrolytic carbon (OPyC) layer thickness measured was 41.2  $\mu\text{m}$  with a standard deviation of 1.9  $\mu\text{m}$ . Top-binned histograms of the distributions of each of these properties are shown in Figure 1Figure 5.

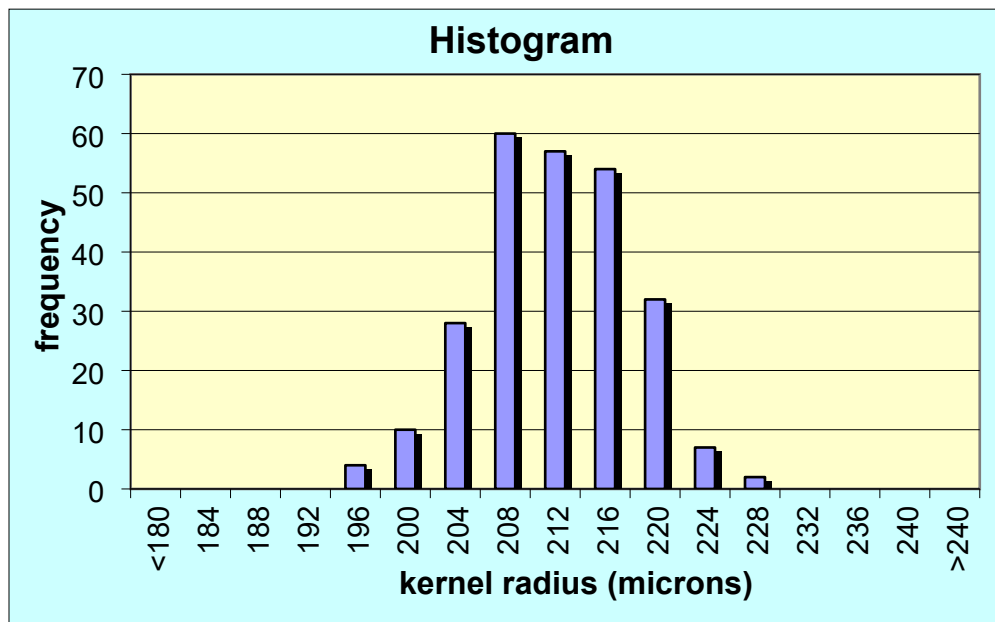


Figure 1. Distribution of kernel radii measured by layer analysis of particles from LEU-09.

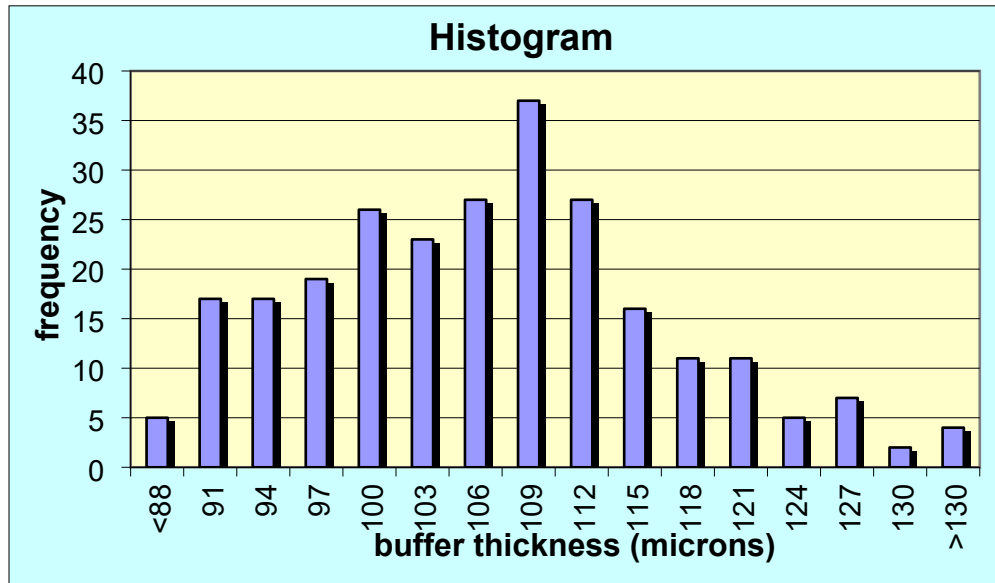


Figure 2. Distribution of buffer layer thicknesses measured by layer analysis of particles from LEU-09.



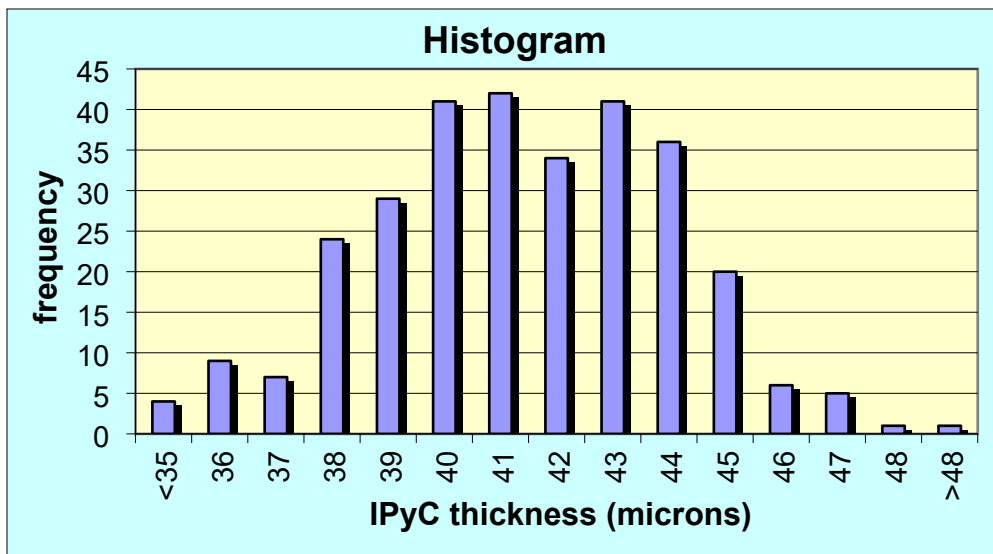


Figure 3. Distribution of IPyC layer thicknesses measured by layer analysis of particles from LEU-09.

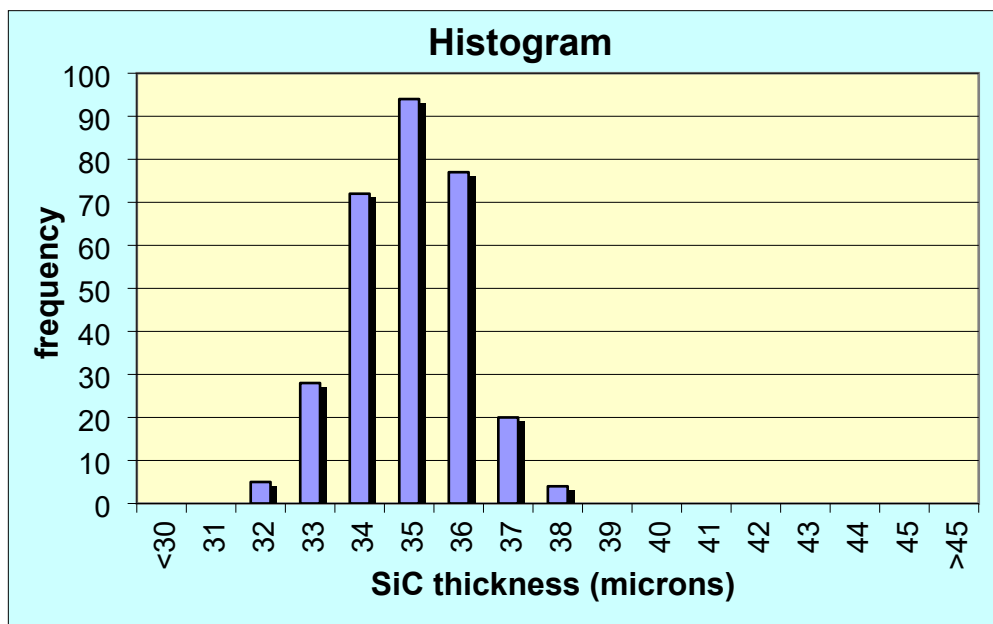


Figure 4. Distribution of SiC layer thicknesses measured by layer analysis of particles from LEU-09.

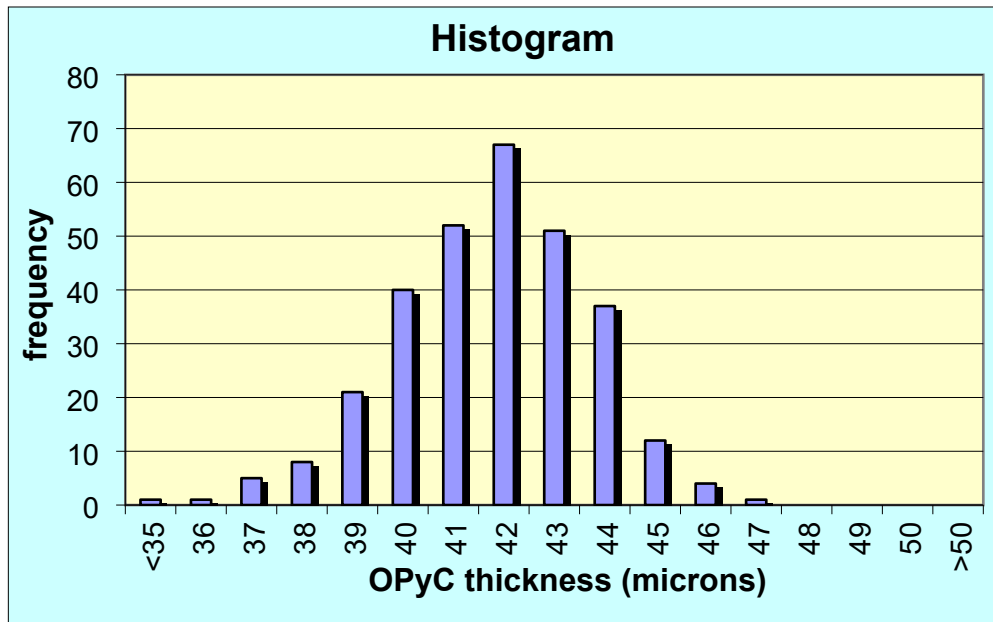


Figure 5. Distribution of OPyC layer thicknesses measured by layer analysis of particles from LEU-09.

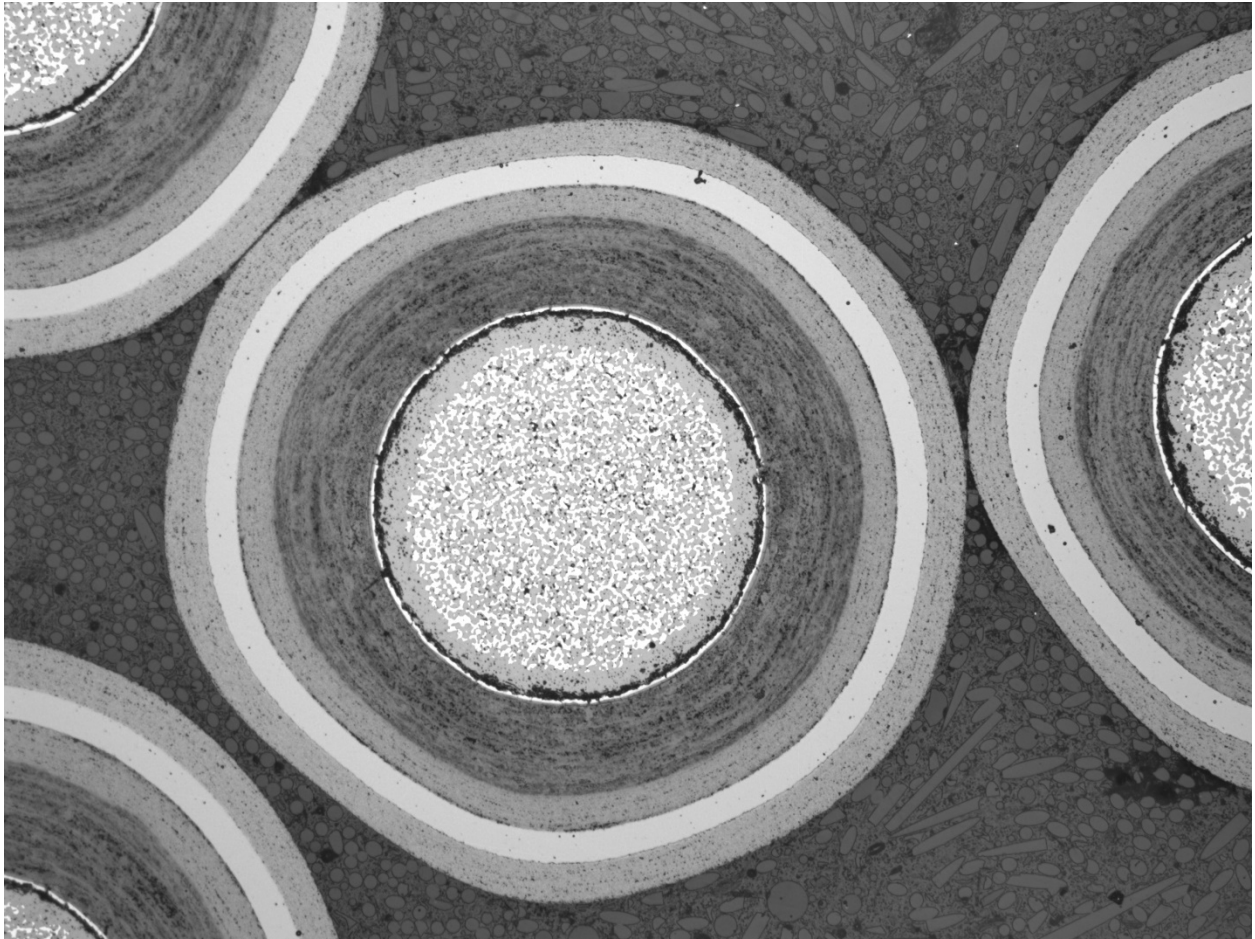


### 3. REFERENCES

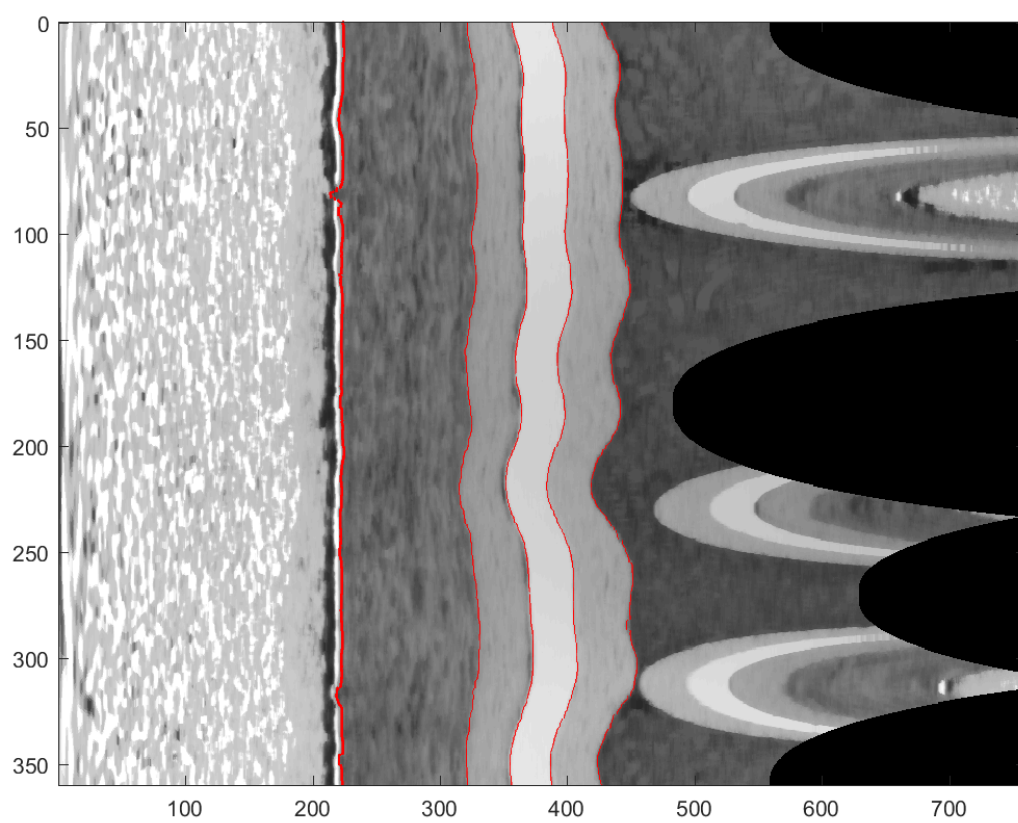
- [1] A. Kercher, J. Hunn, J. Price and P. Pappano, "Automated optical microscopy of coated particle fuel," *Journal of Nuclear Materials*, vol. 380, pp. 76-84, 2008.

## APPENDIX A. RAW IMAGES FOR LAYER THICKNESS ANALYSIS

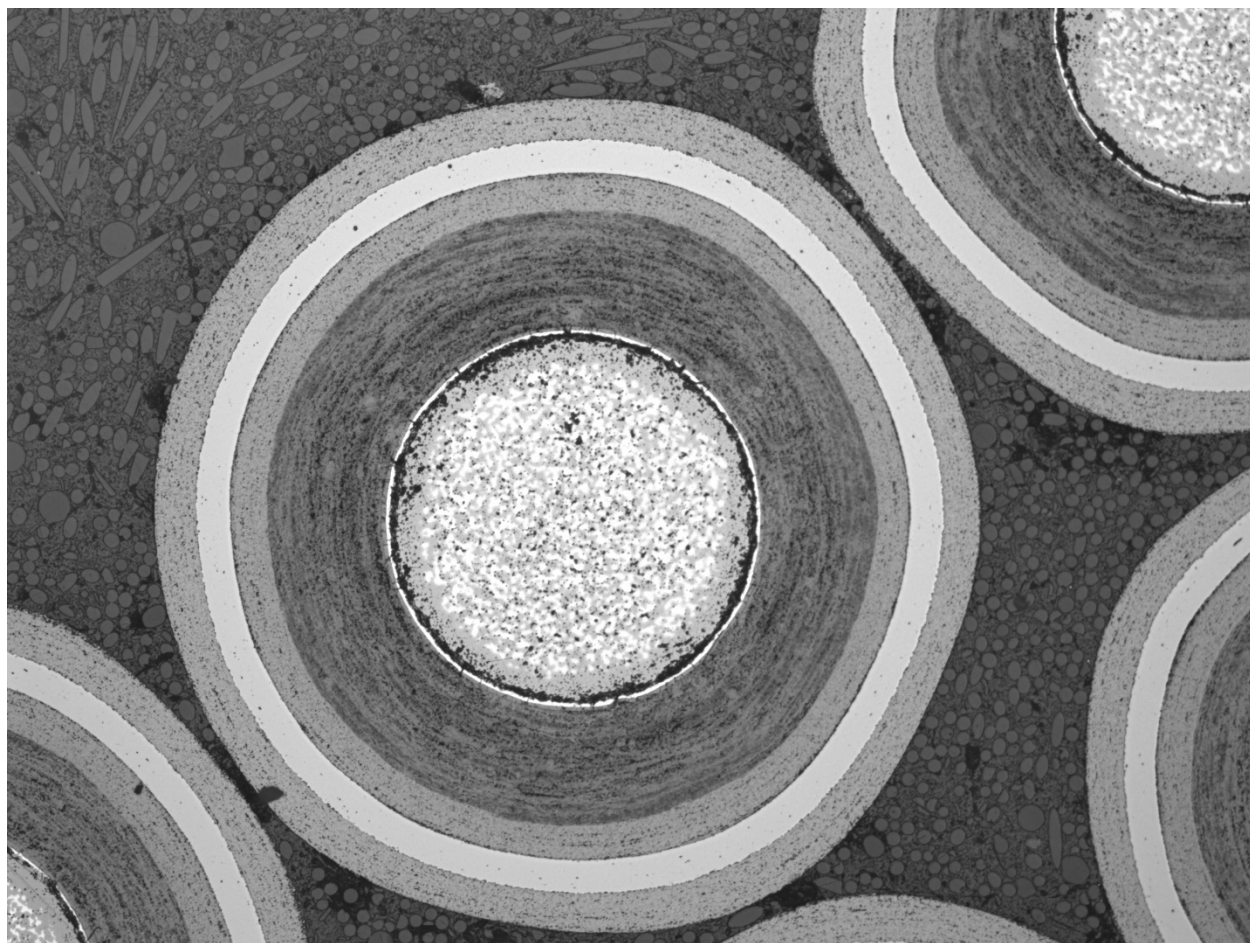
Images in this appendix are presented in the same order as the raw data provided in Appendix B. In each case, original image is presented first and the unwrapped (i.e., cartesian-to-polar transformed) image with layer boundaries marked in red is presented second.



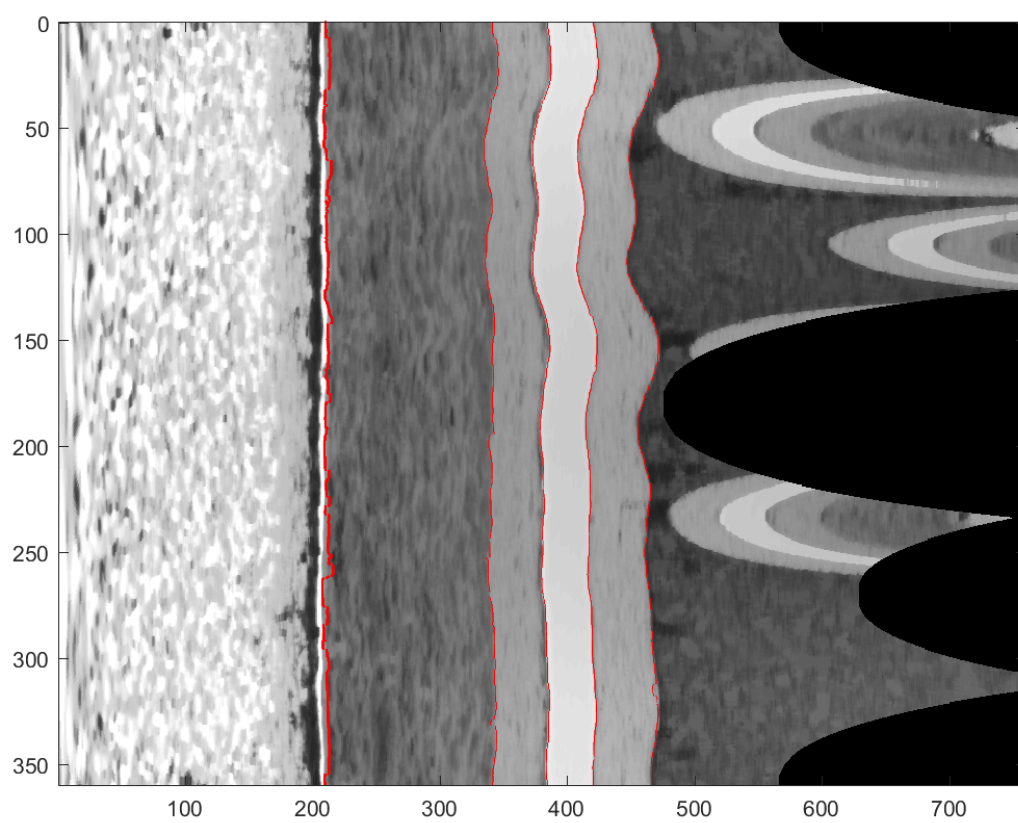
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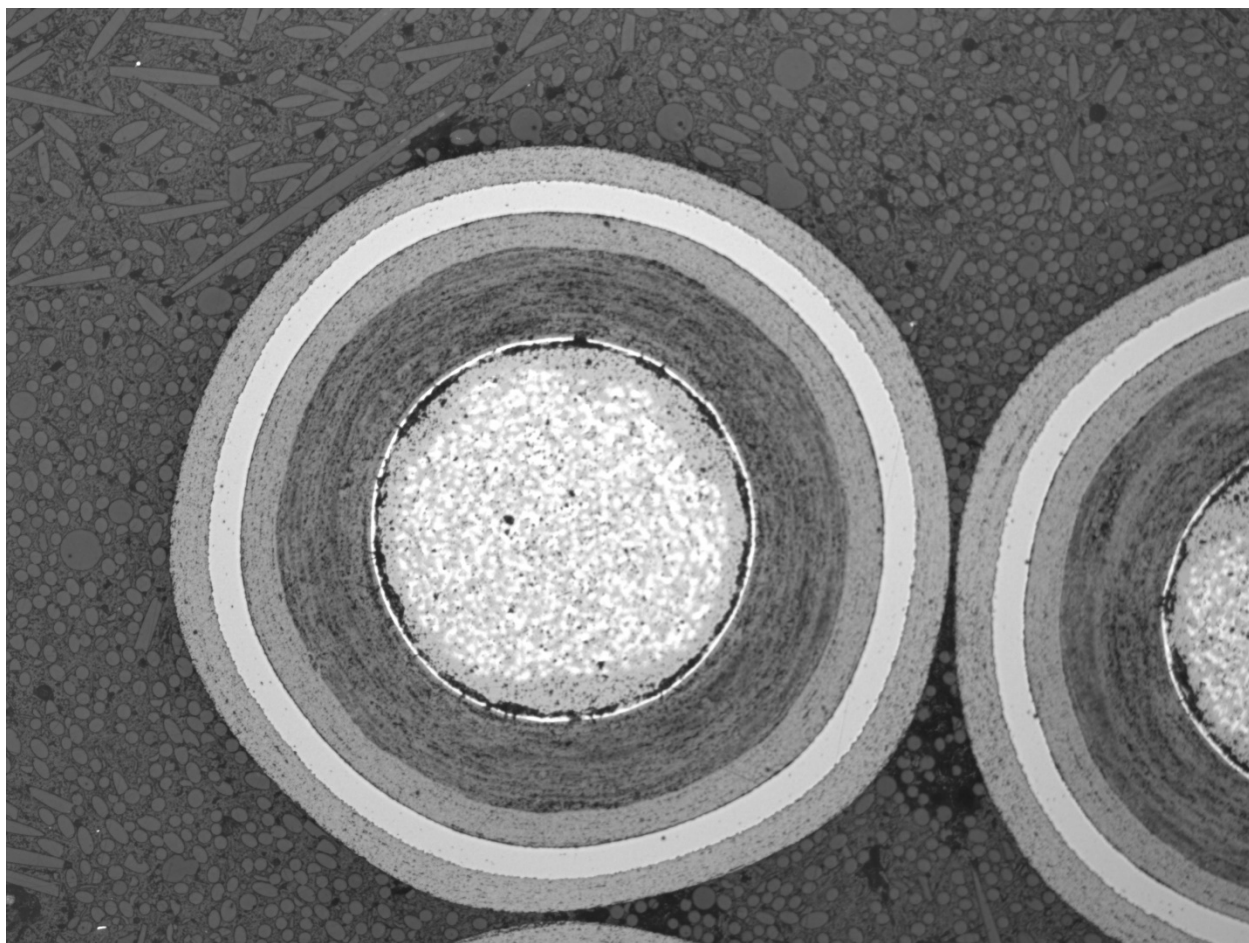
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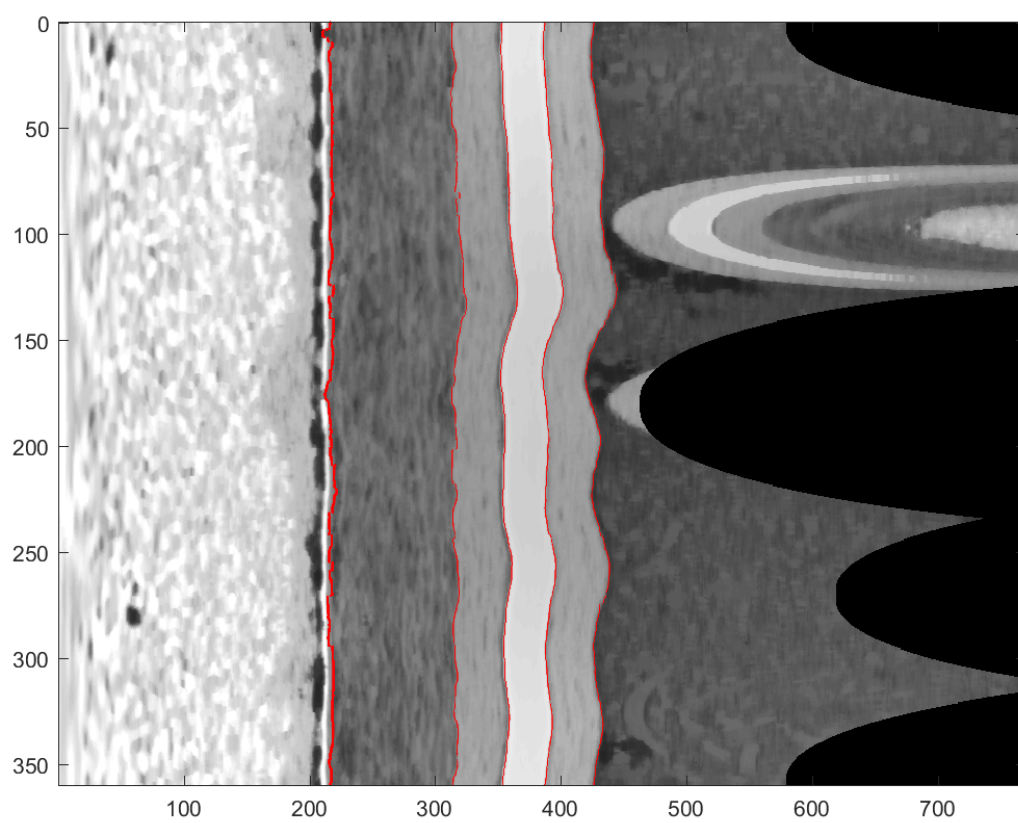
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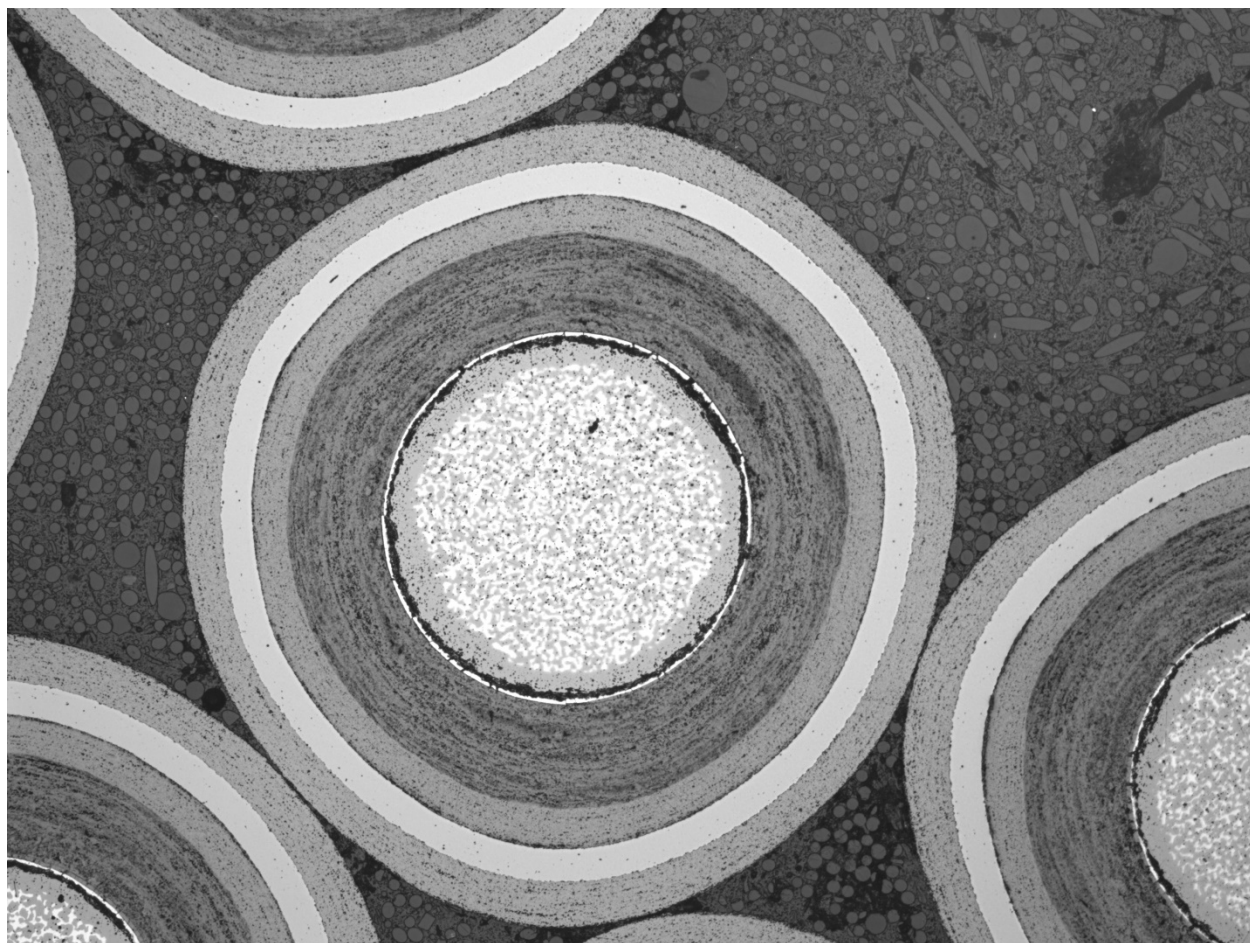


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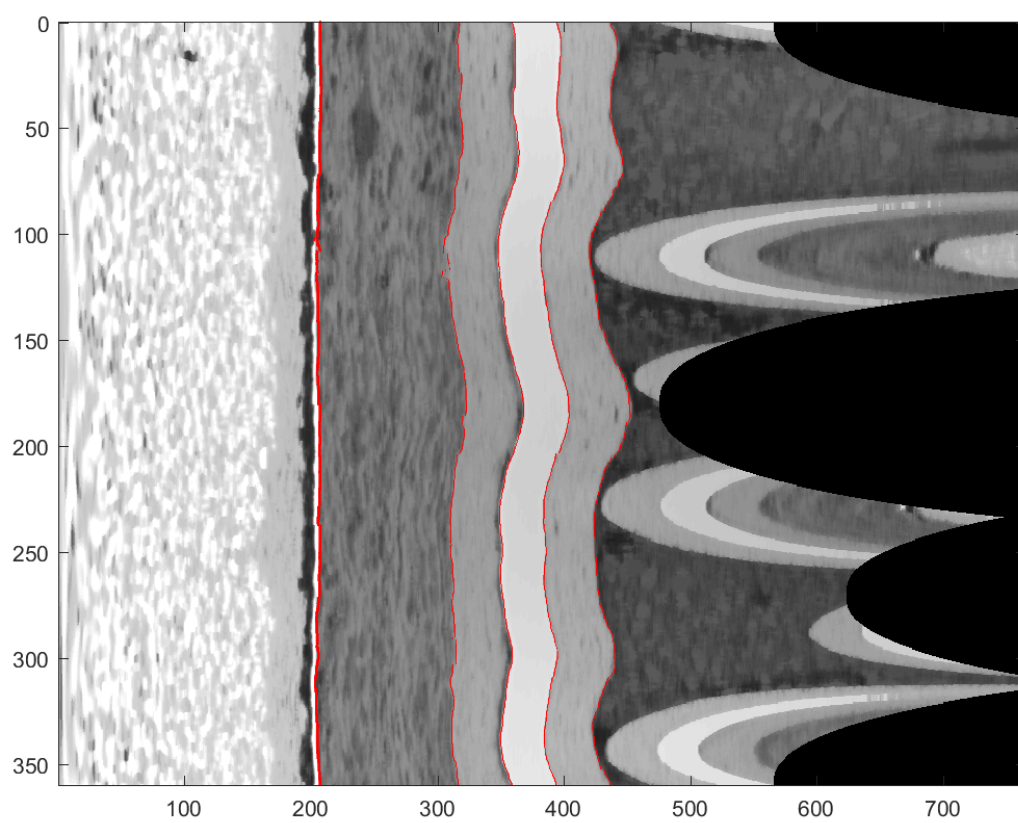


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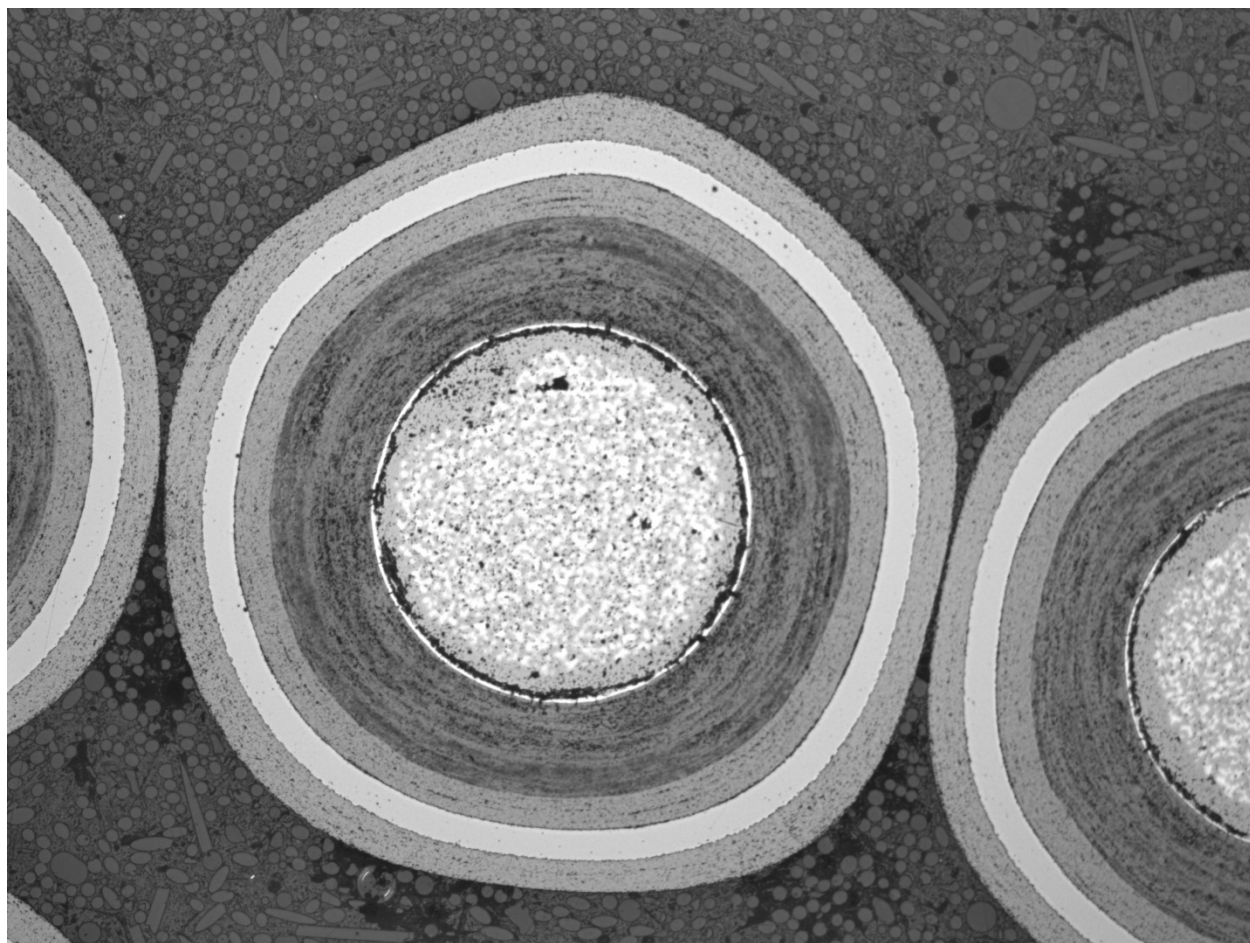




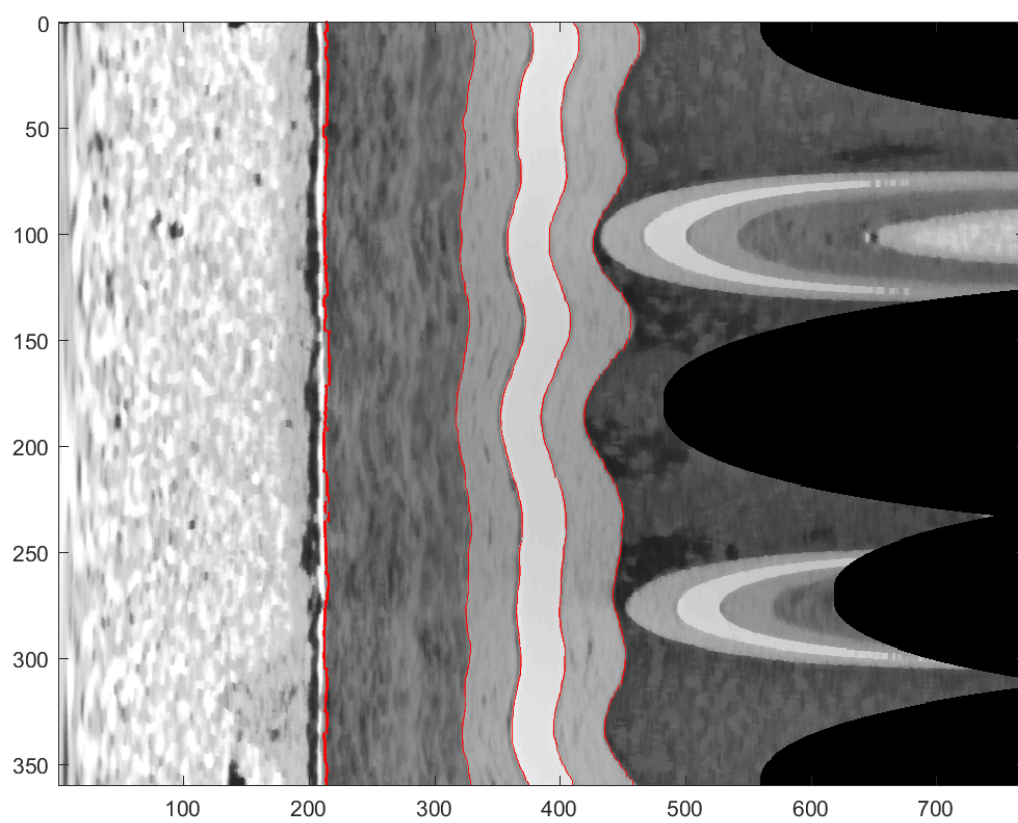
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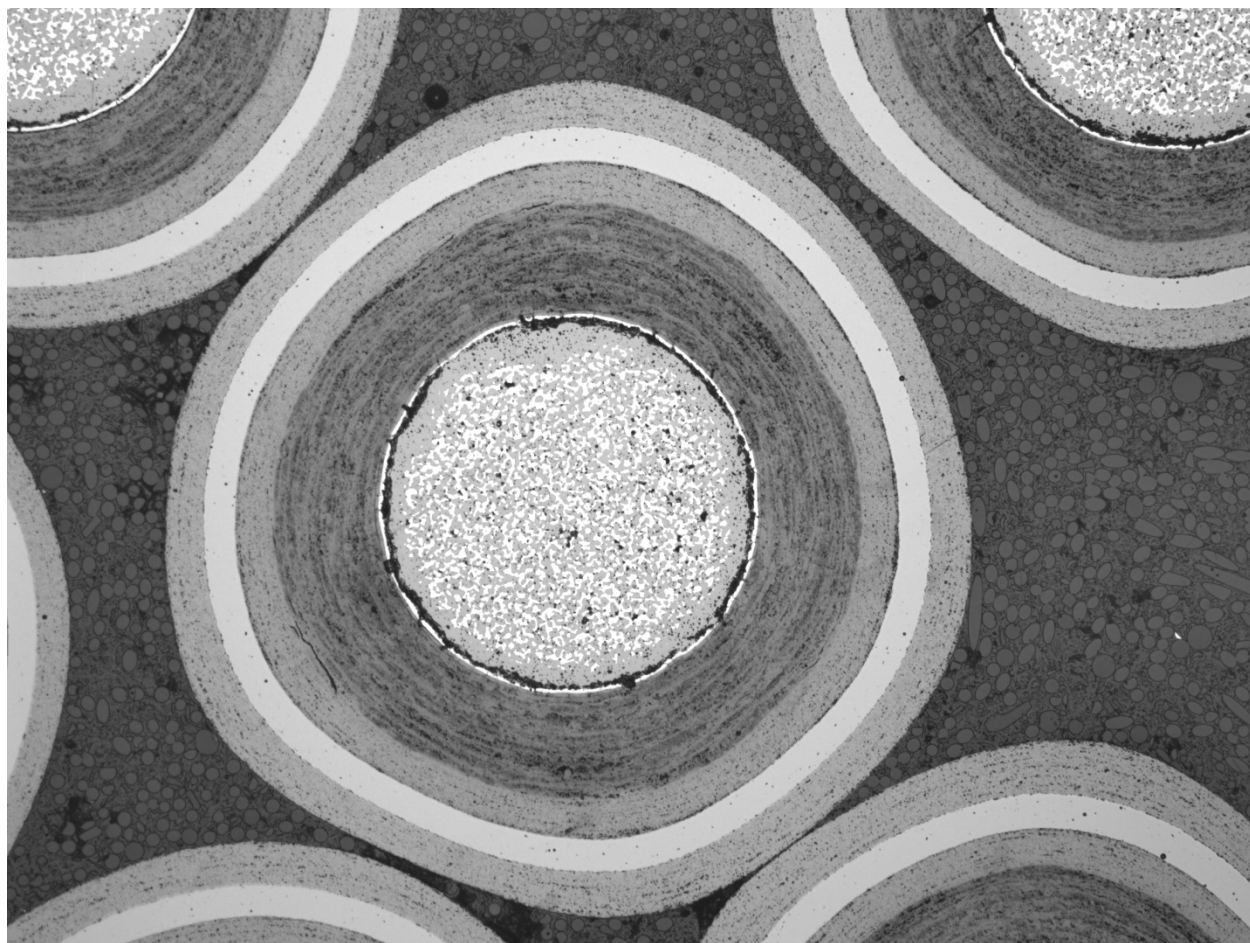
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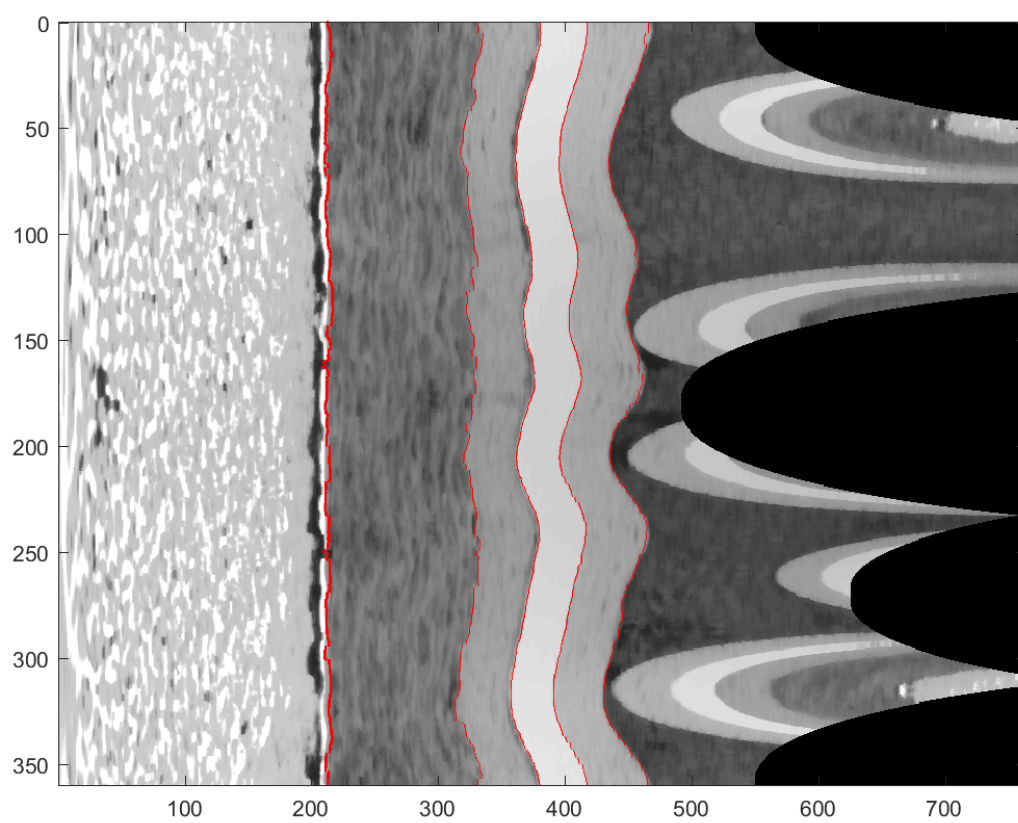
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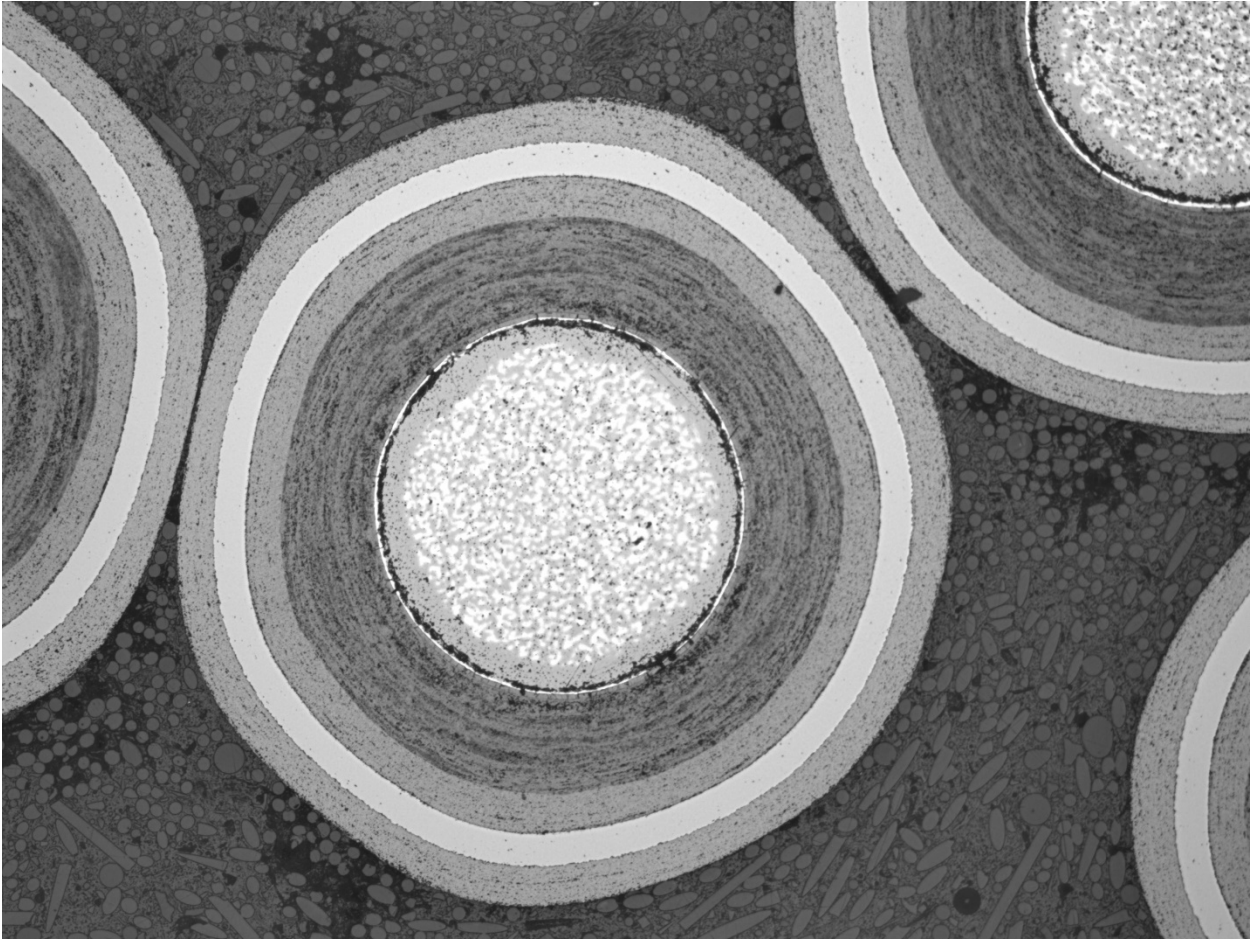


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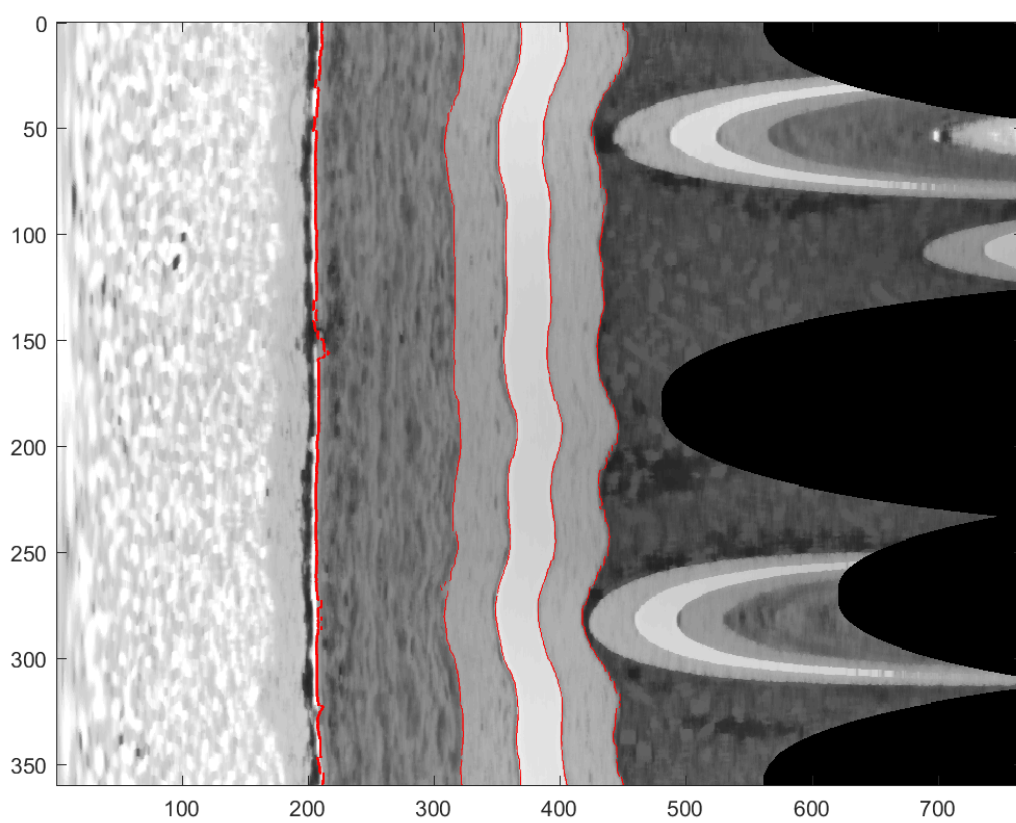


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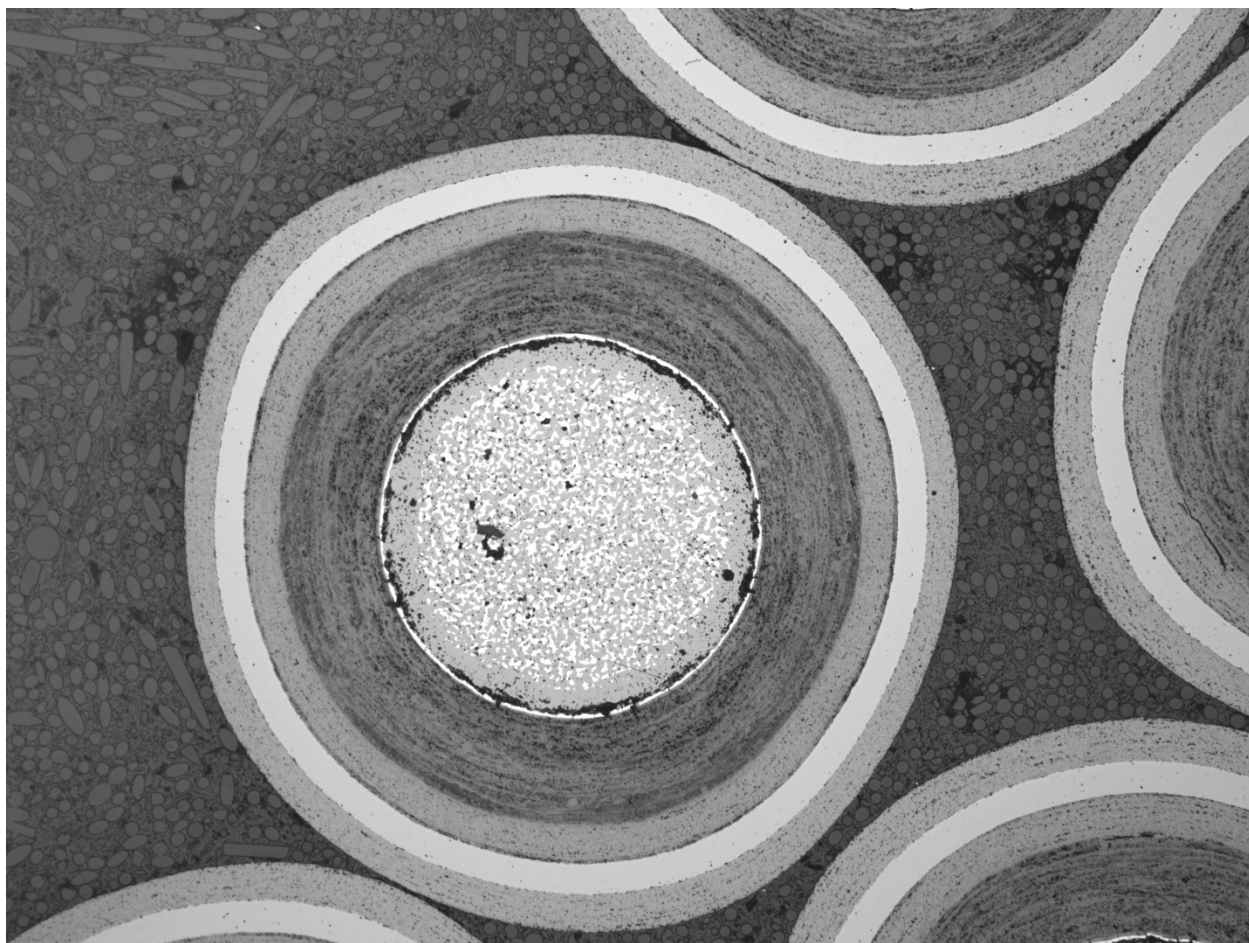


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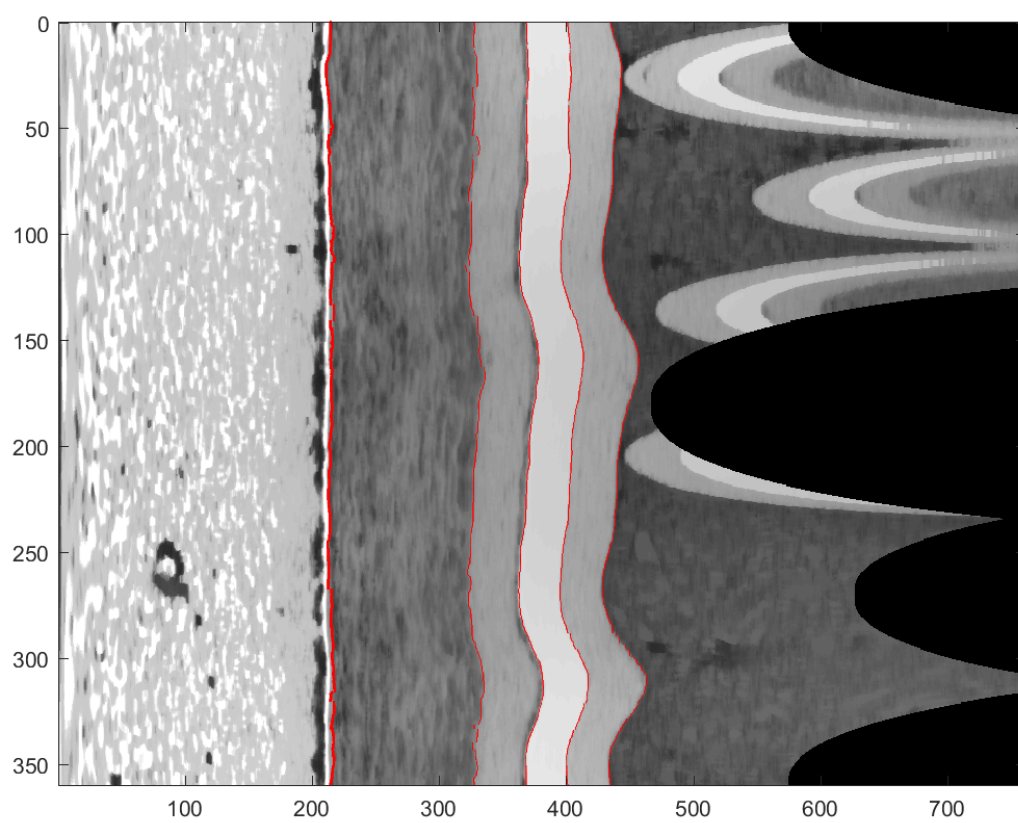


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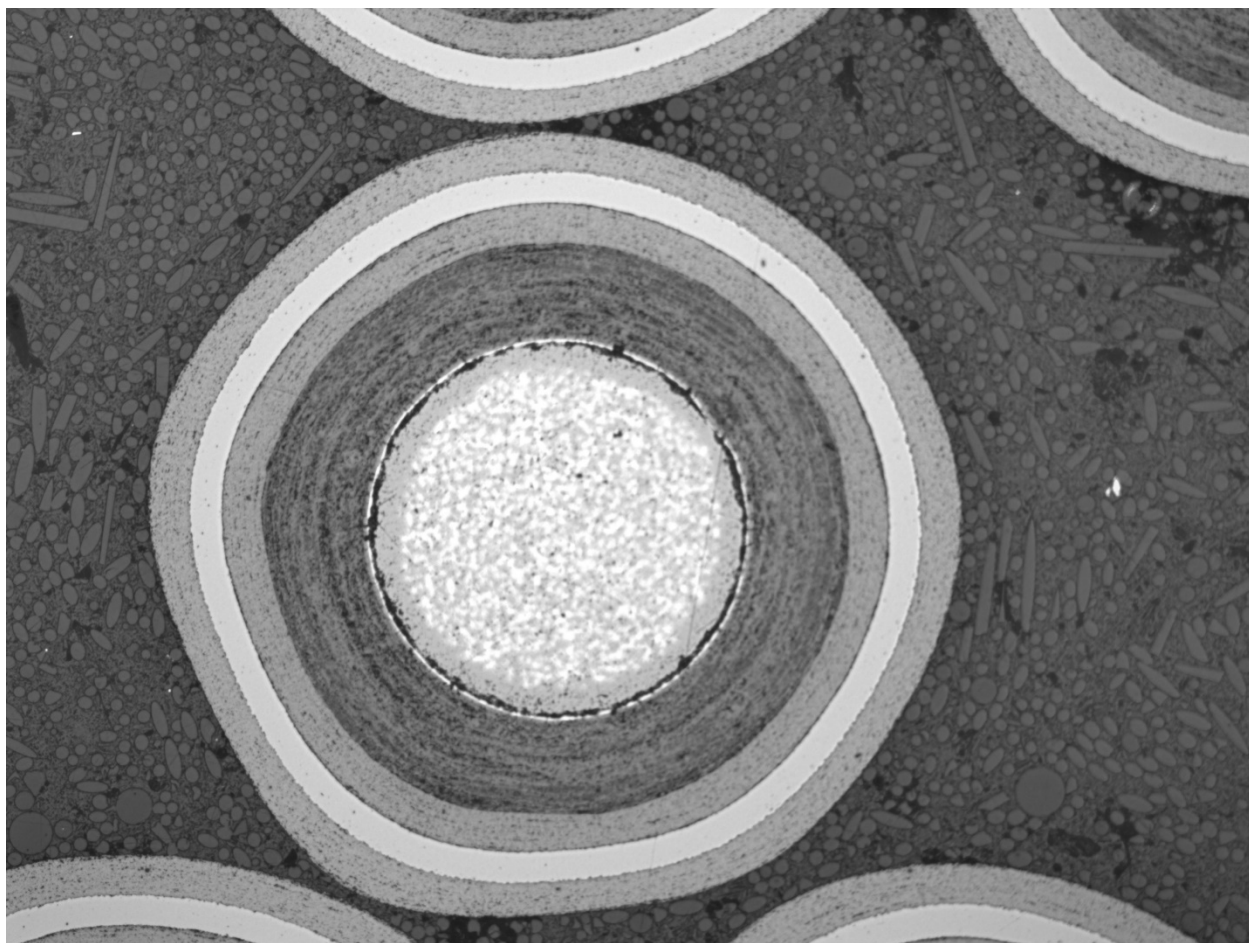




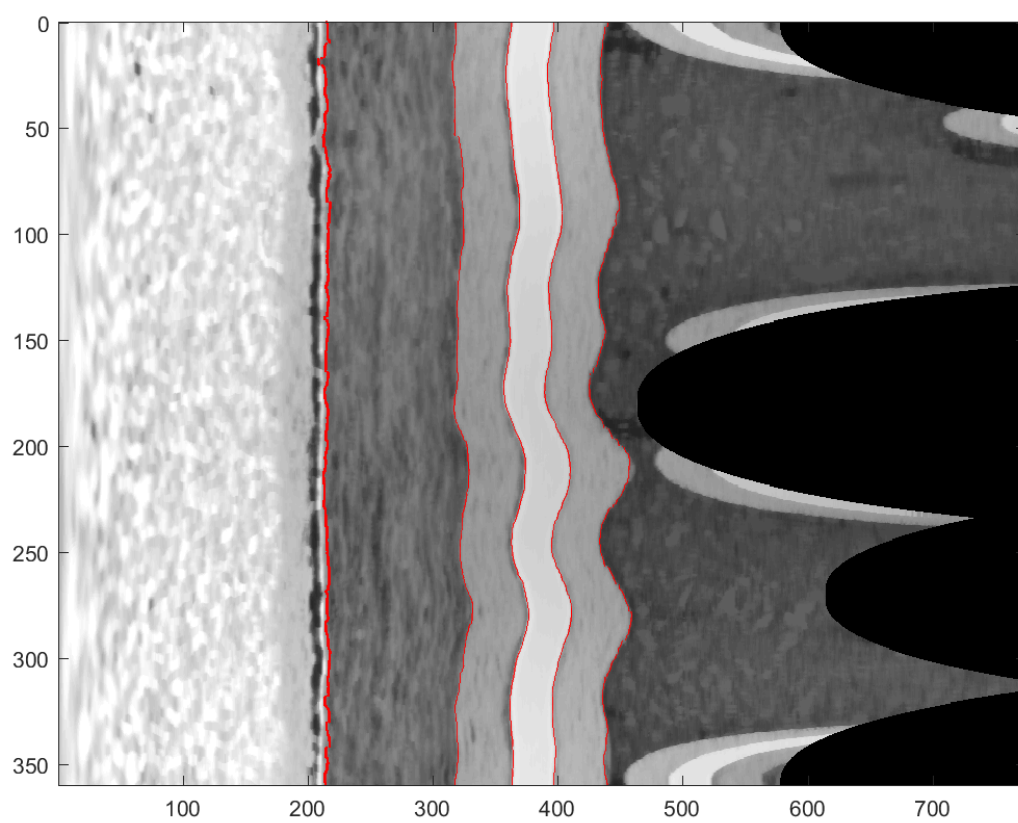
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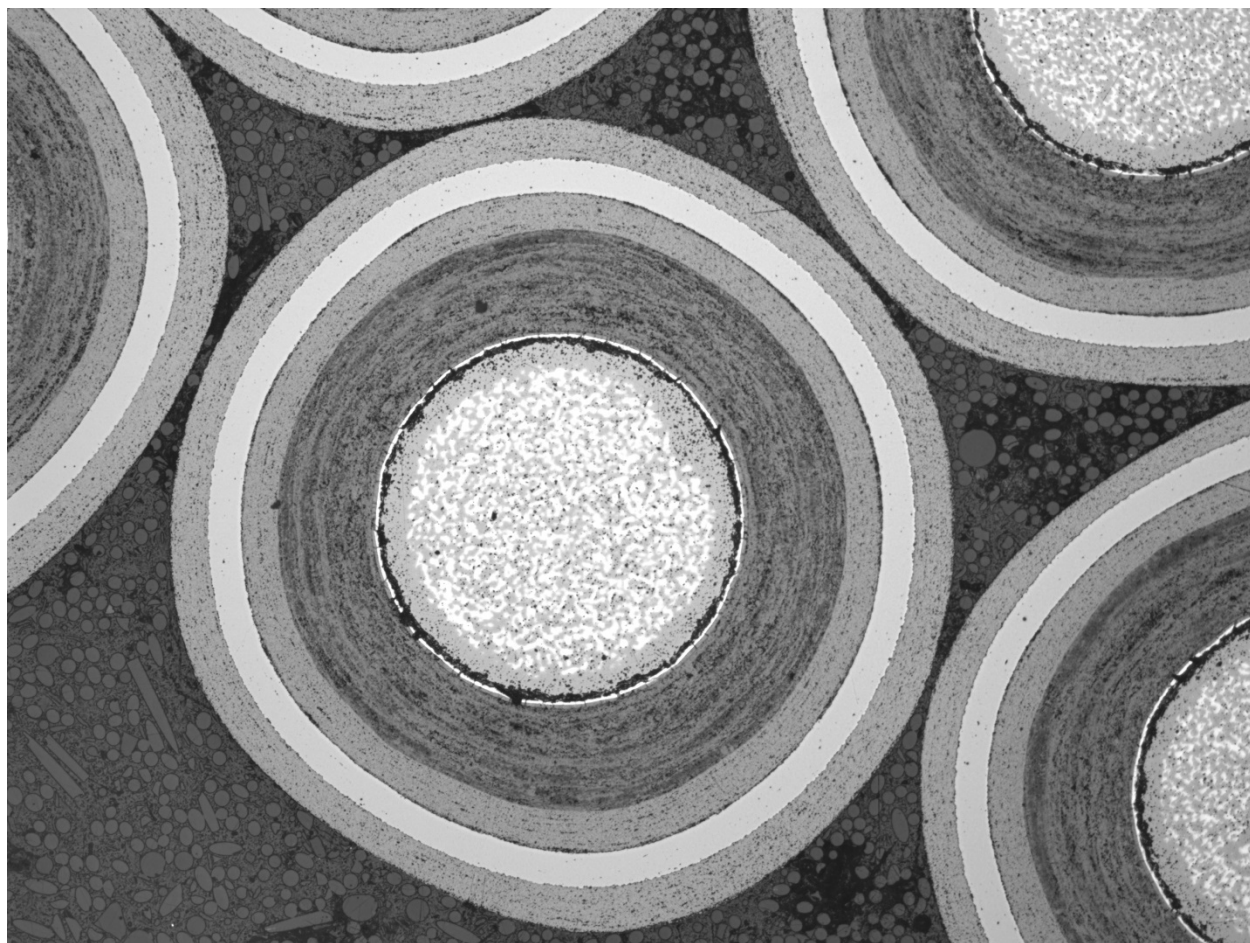
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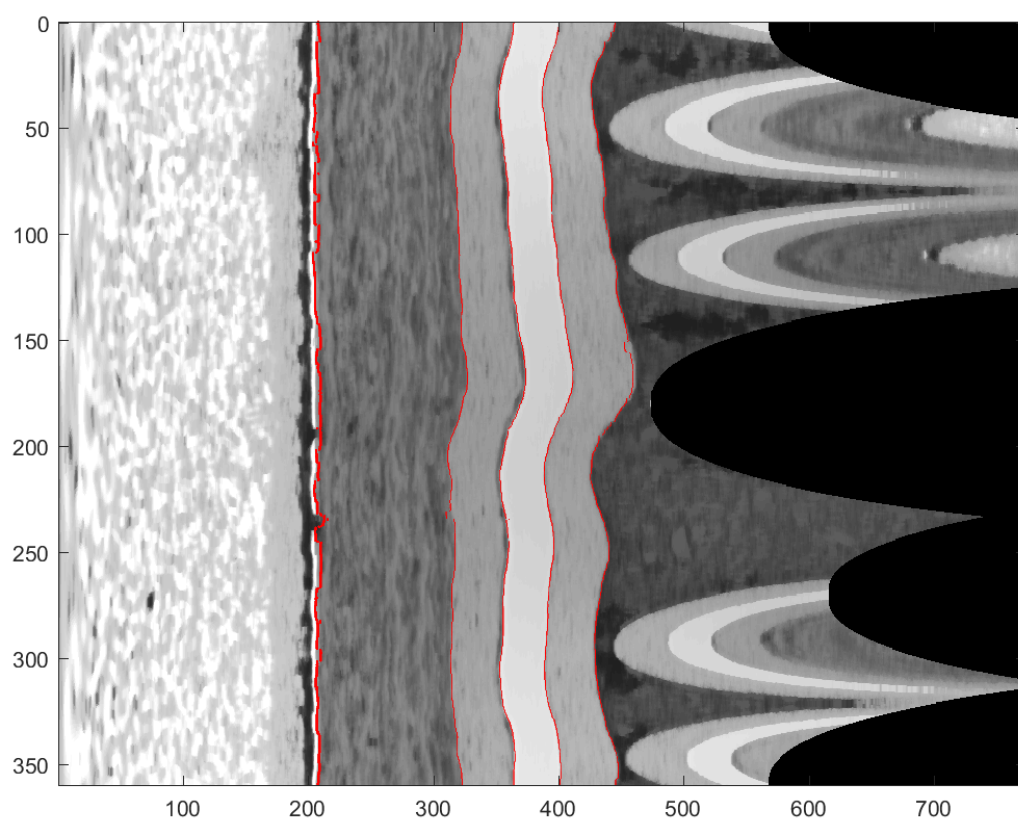
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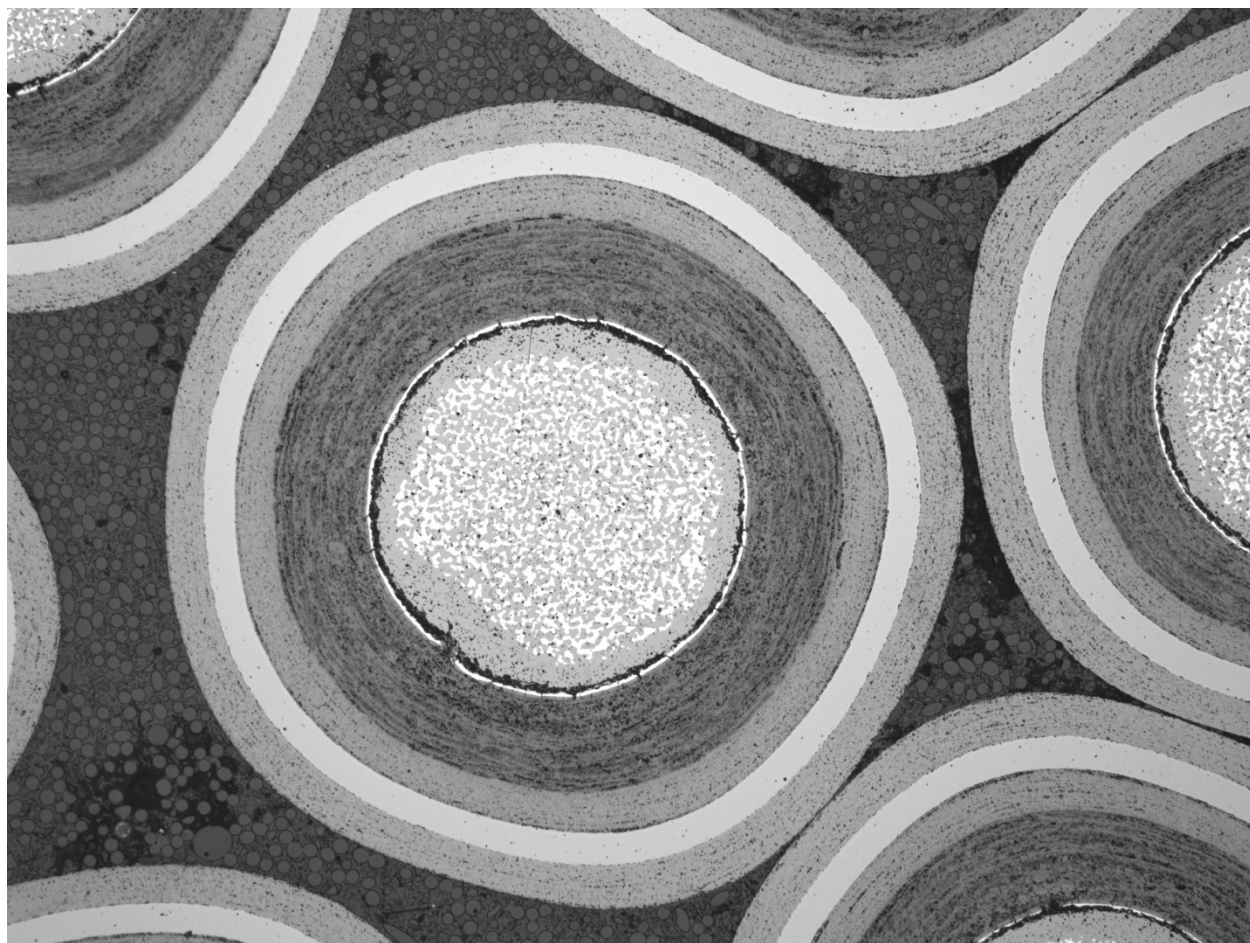


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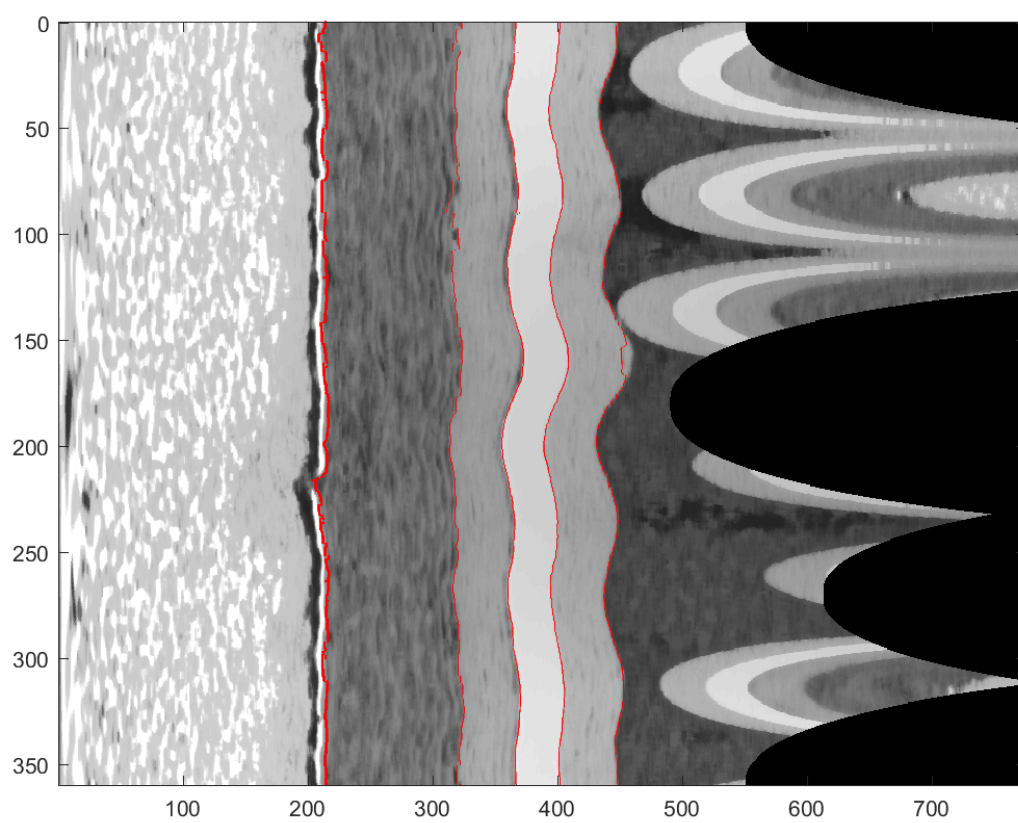


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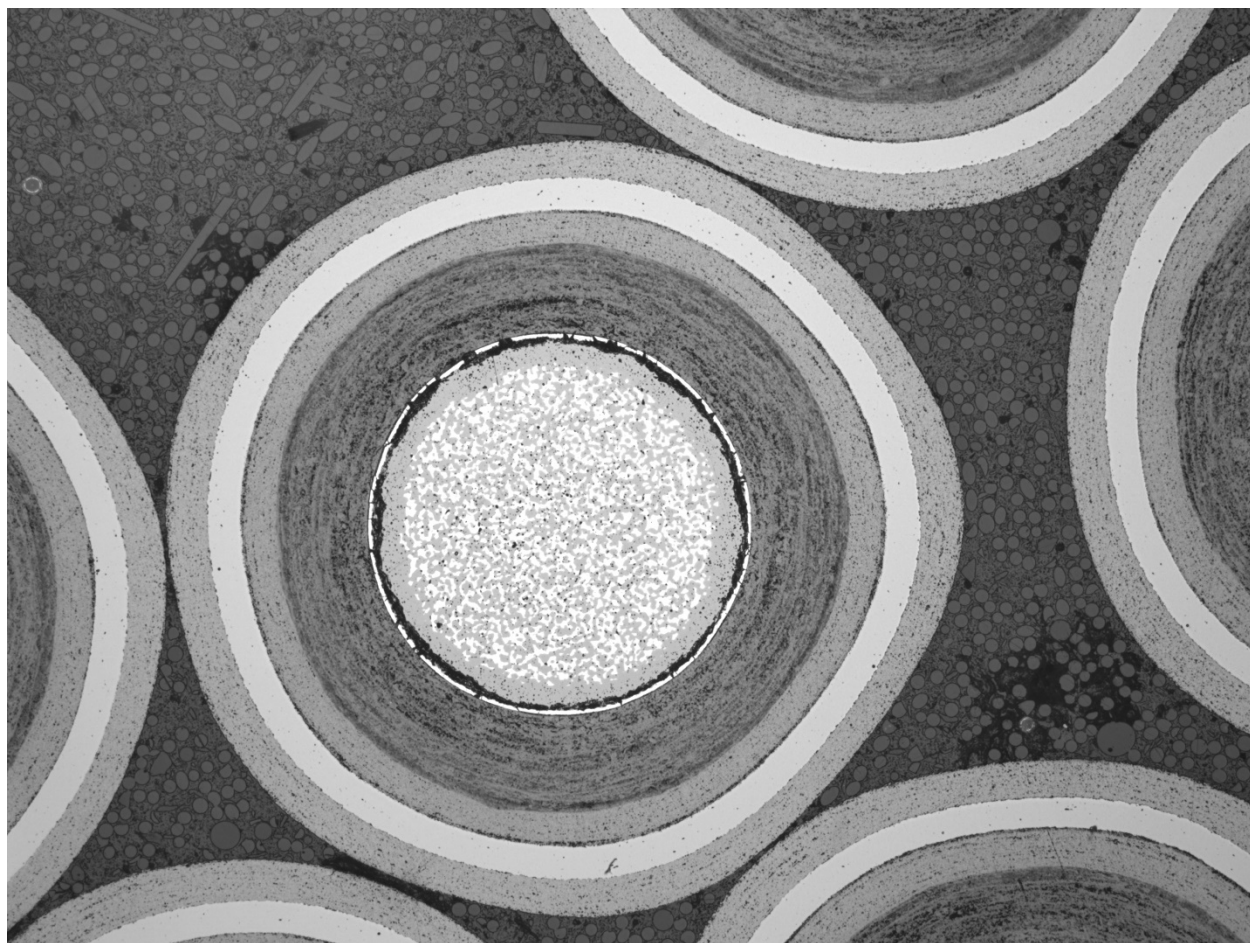


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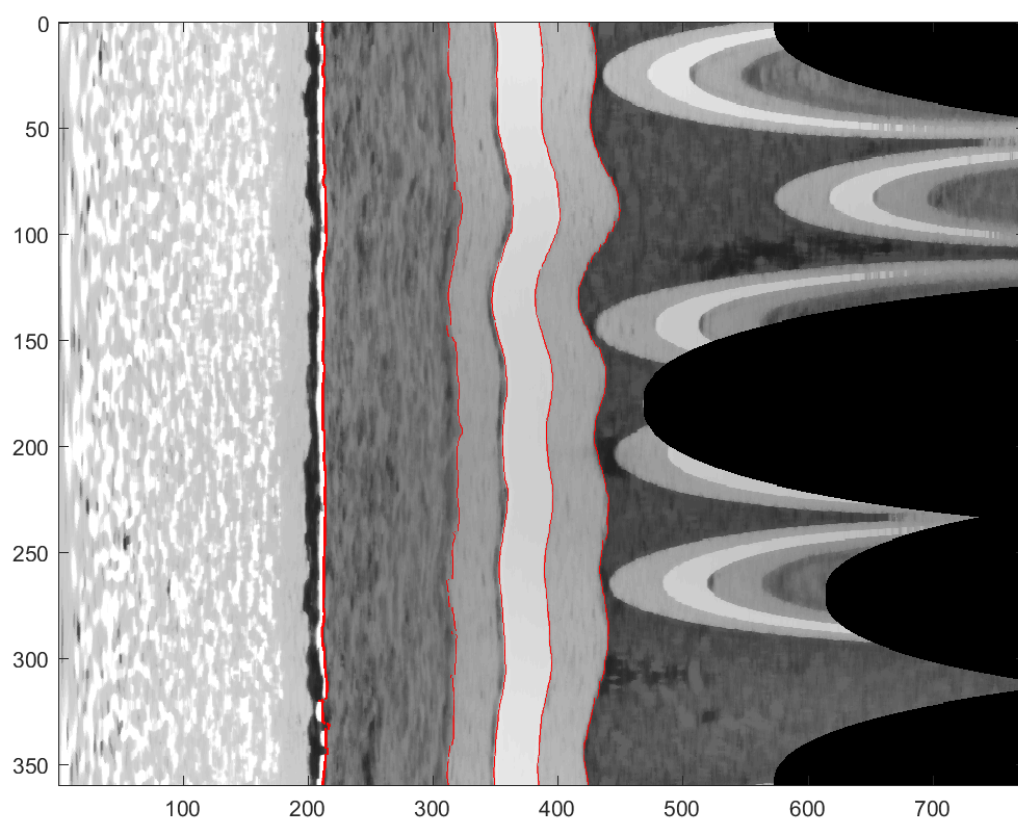


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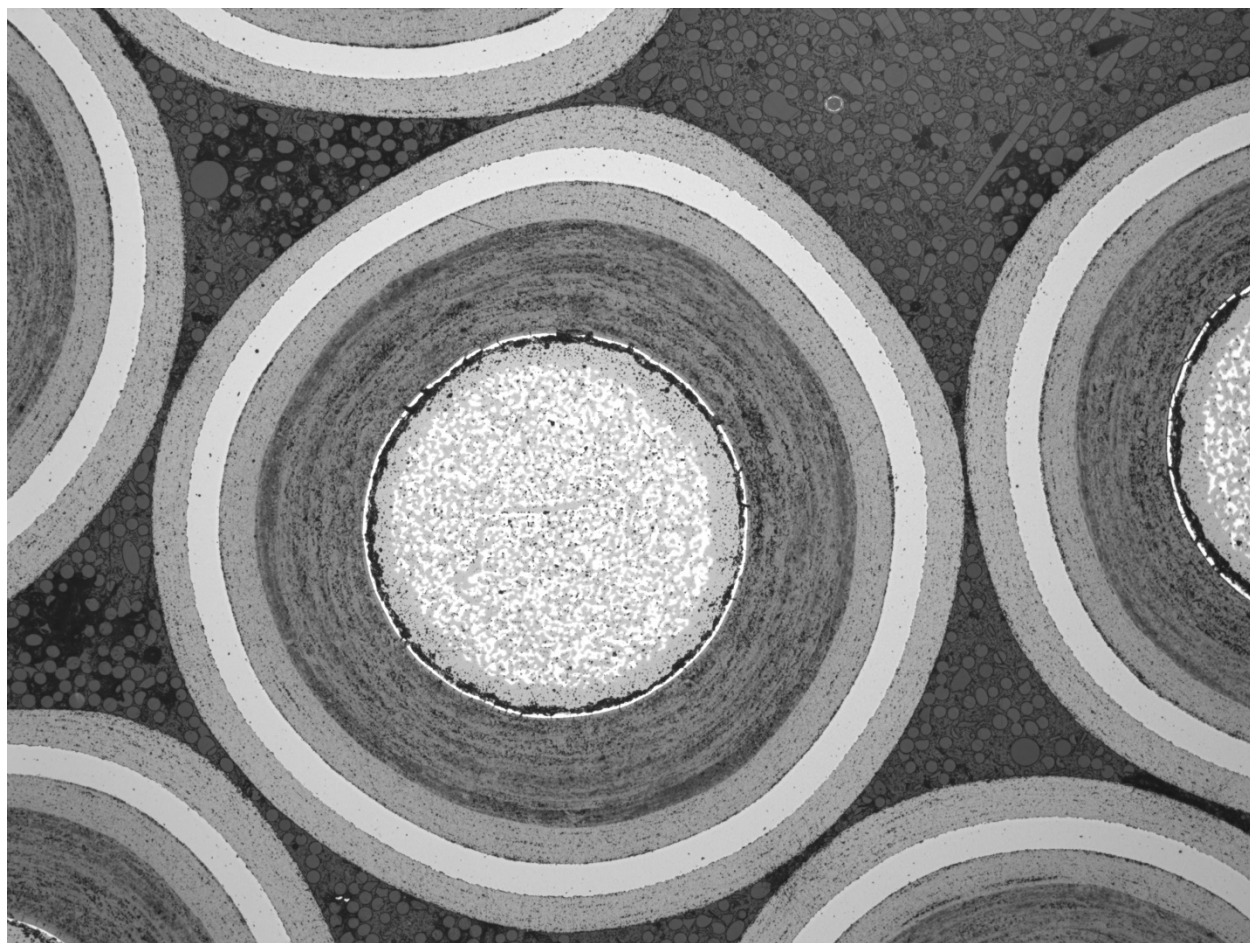




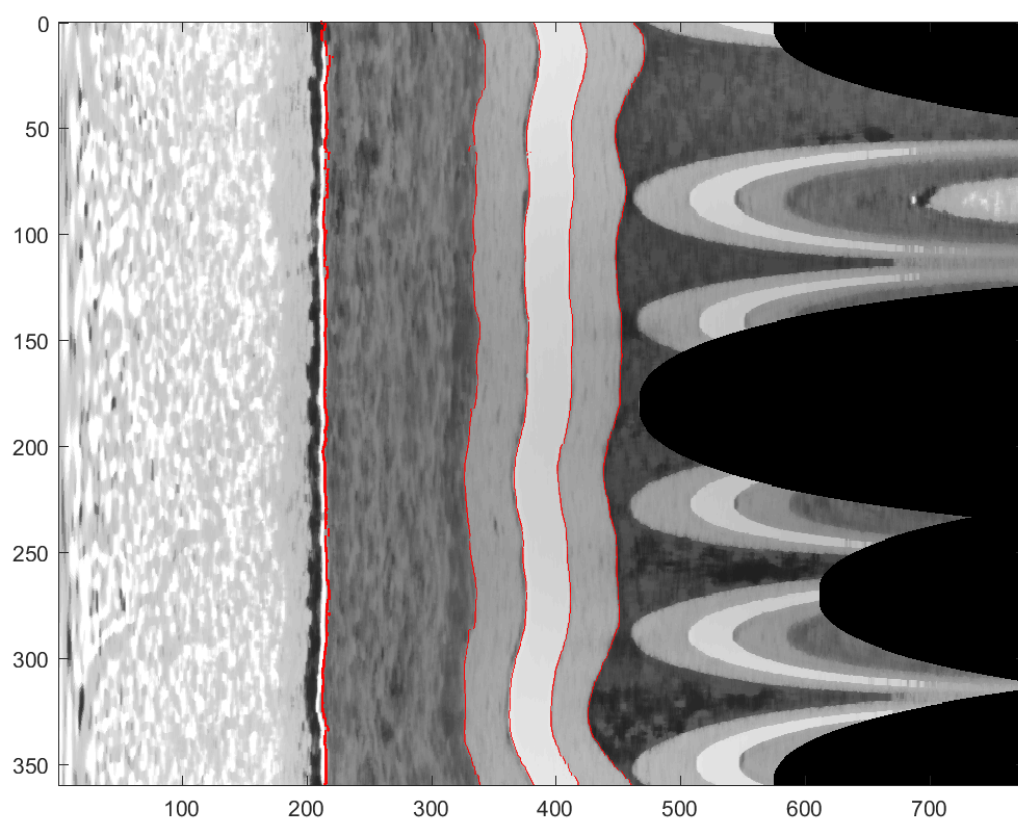
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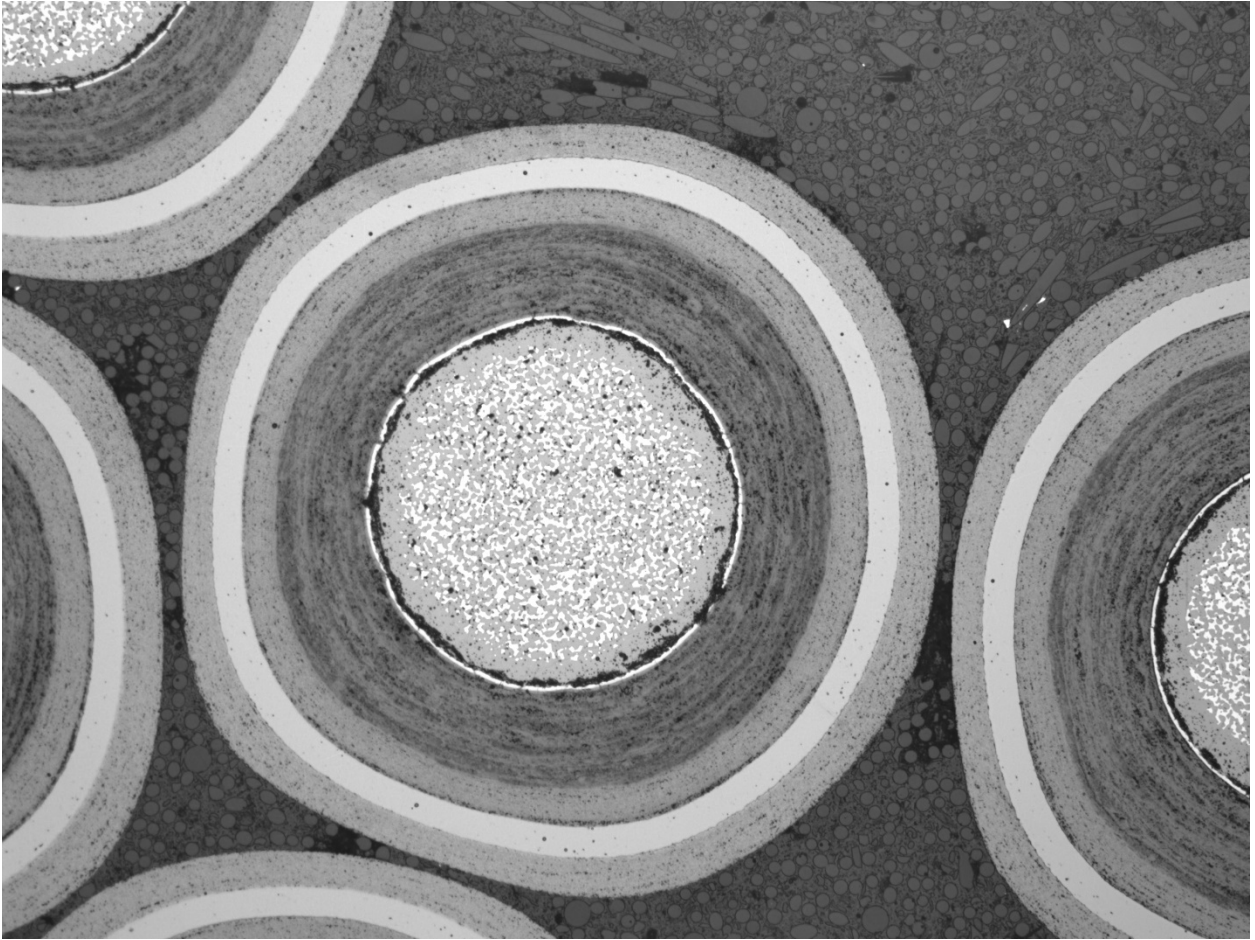
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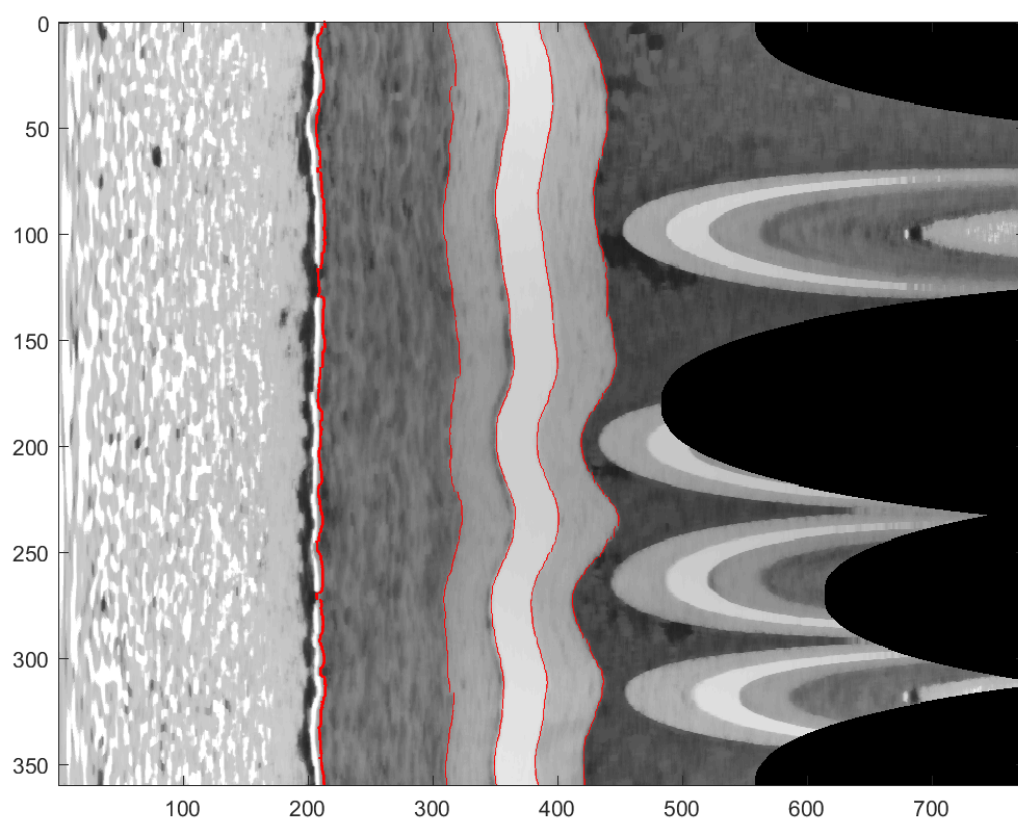
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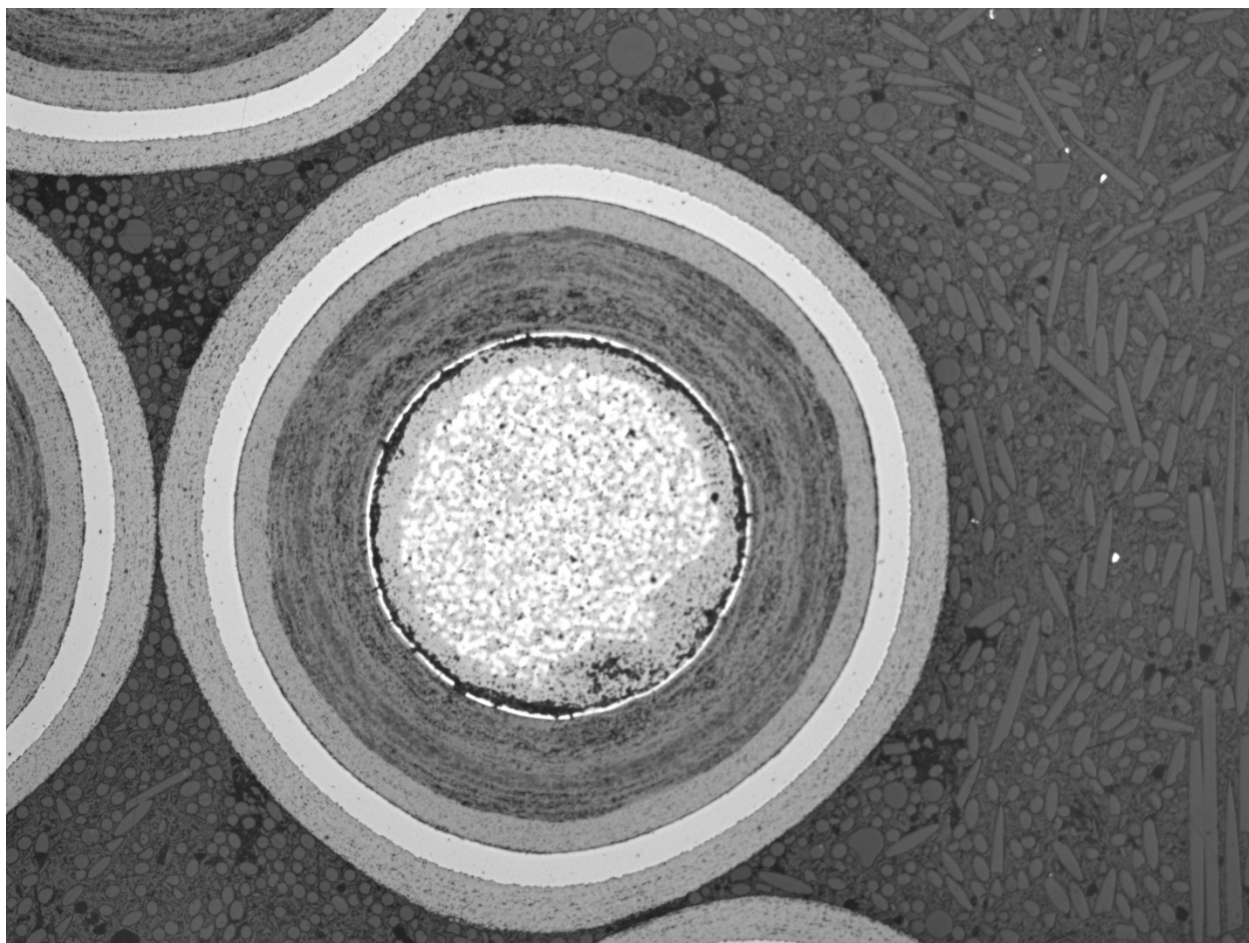


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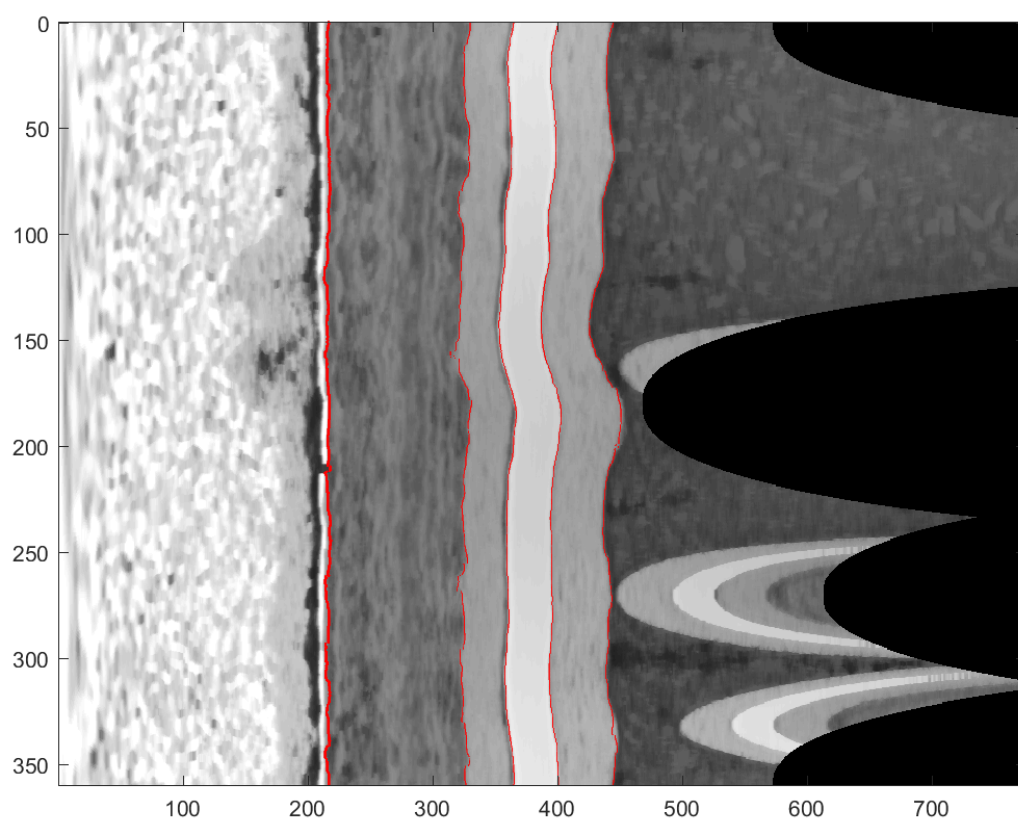


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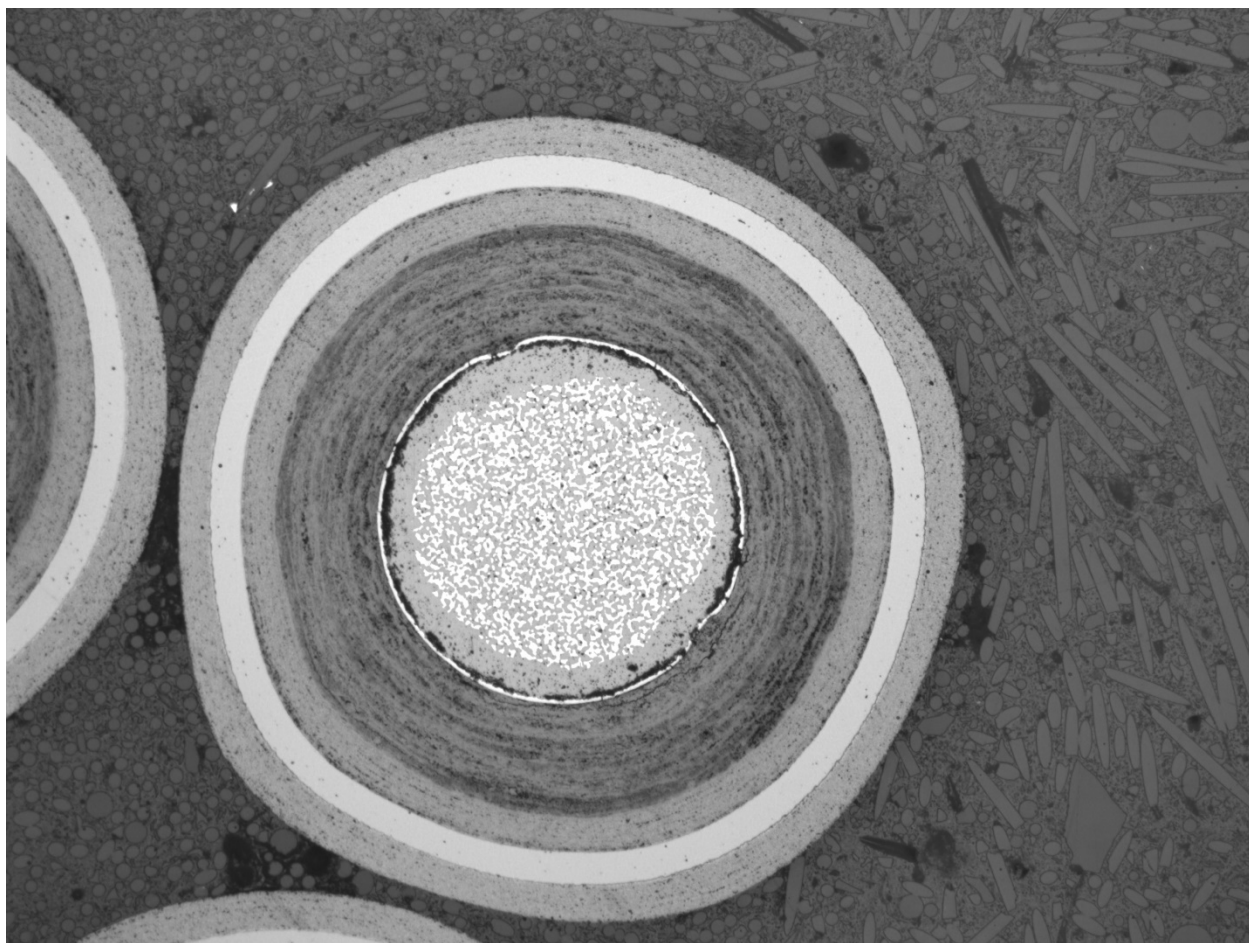


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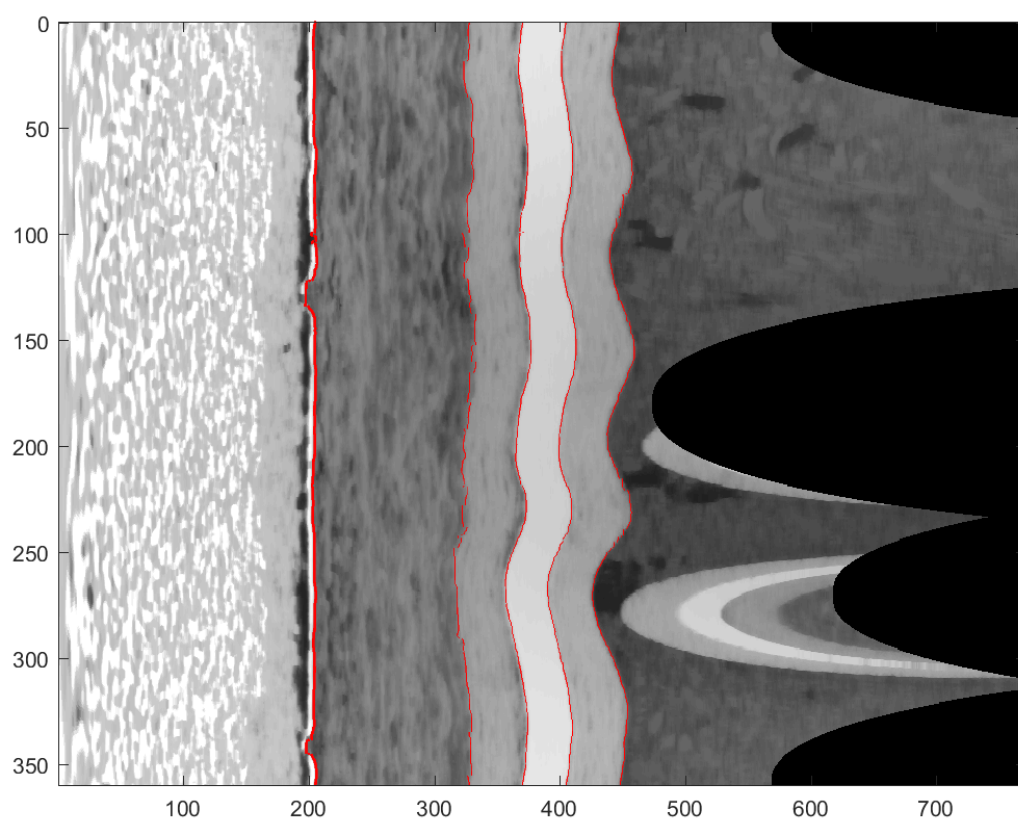


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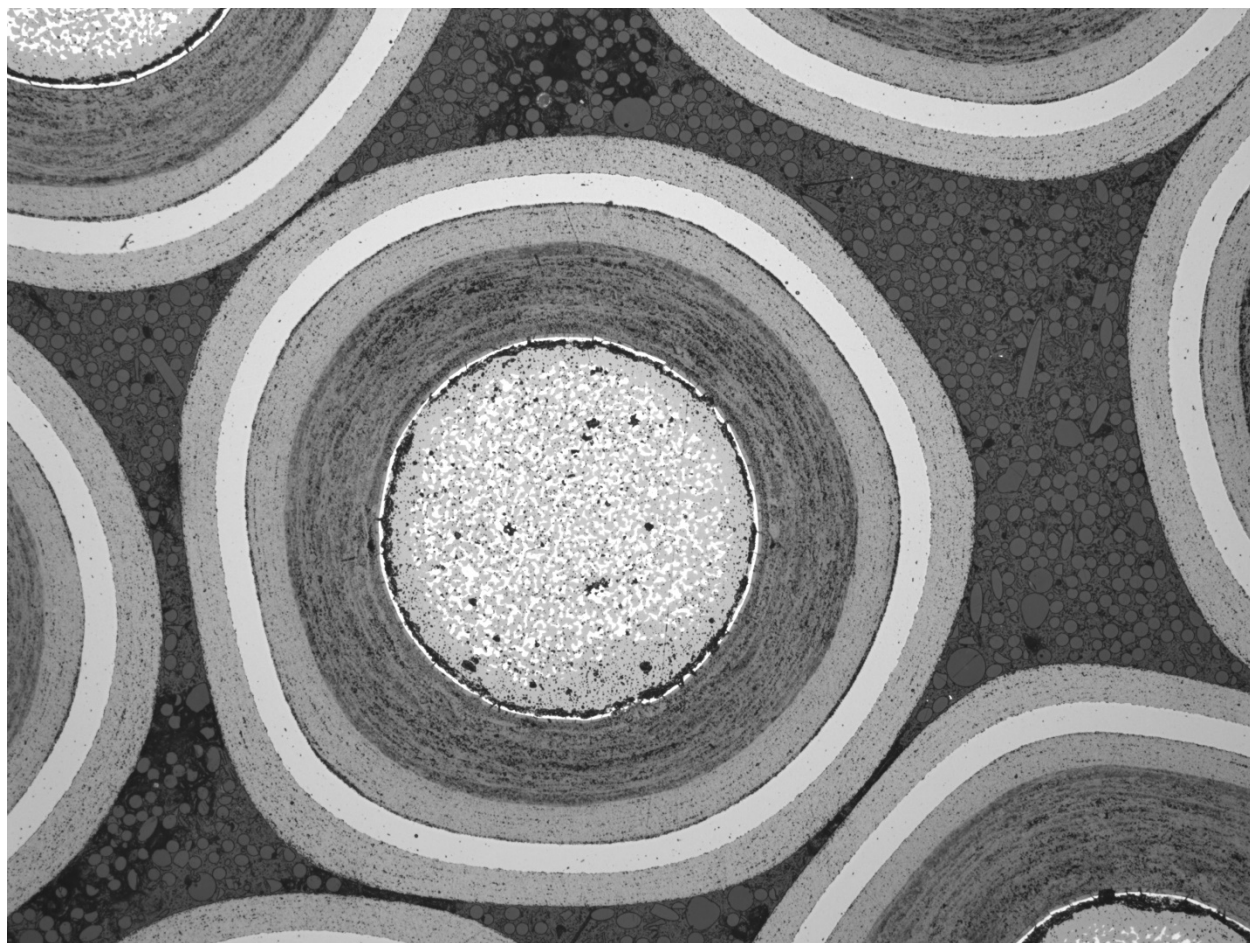




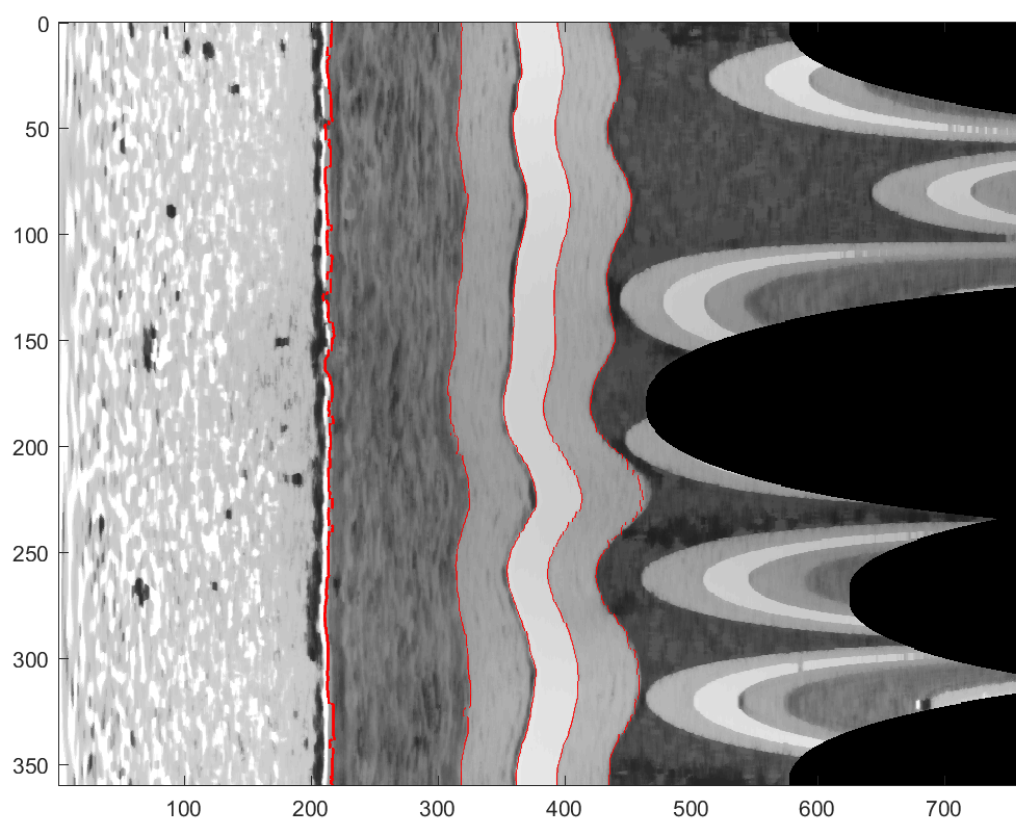
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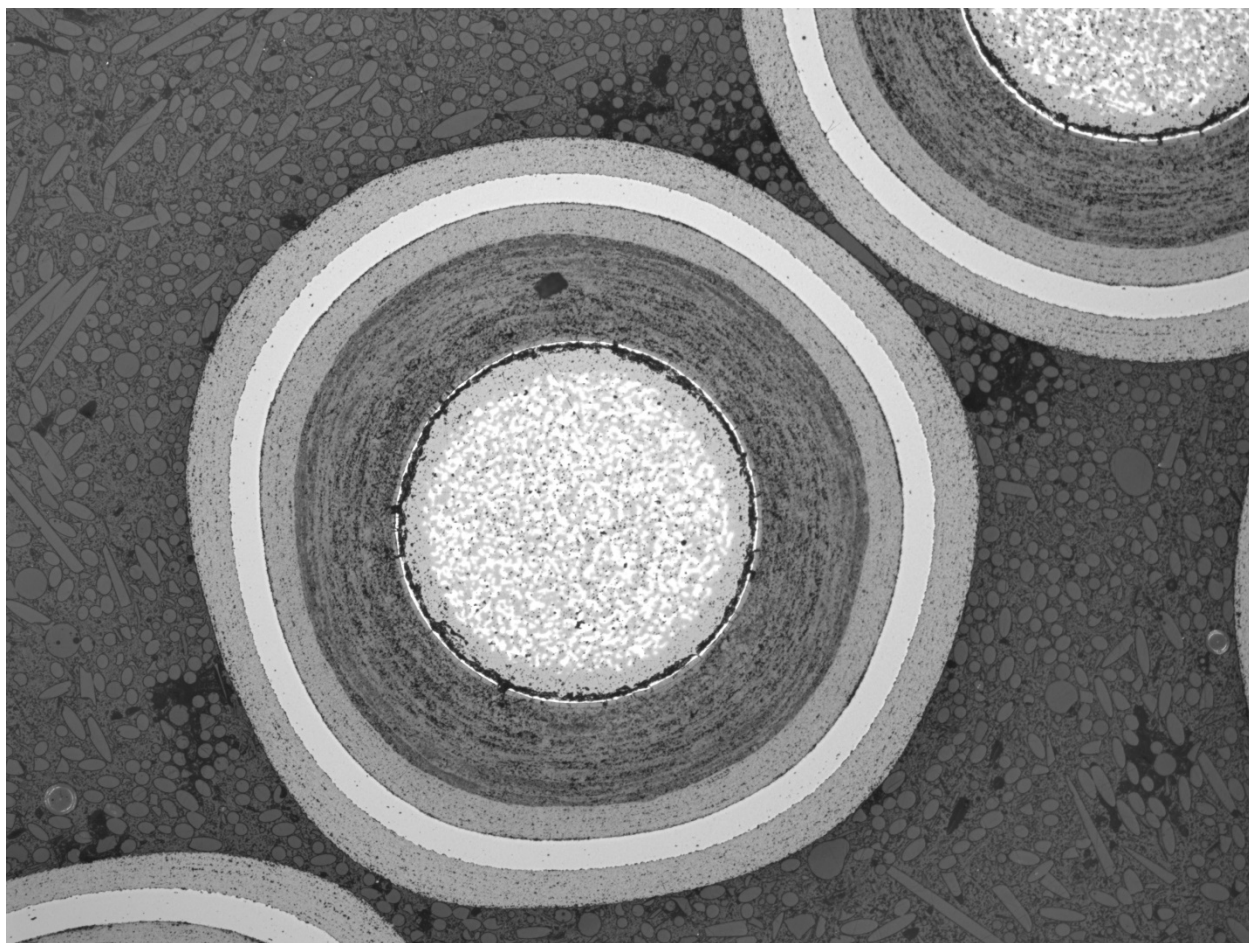
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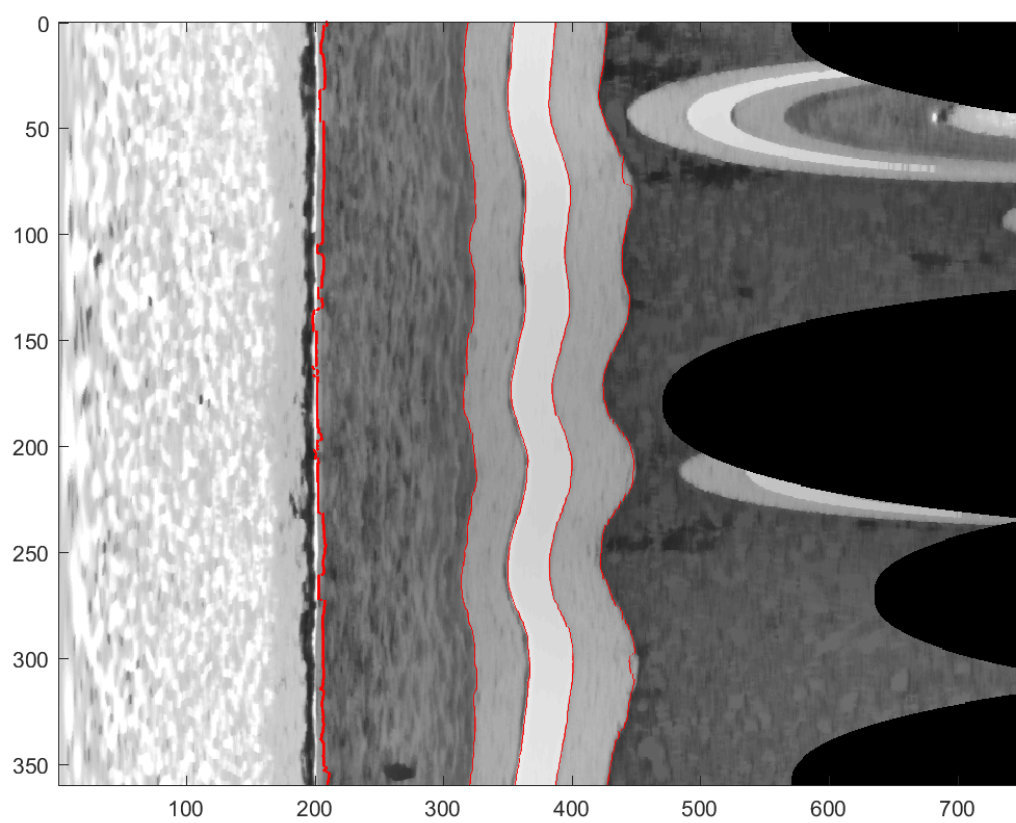
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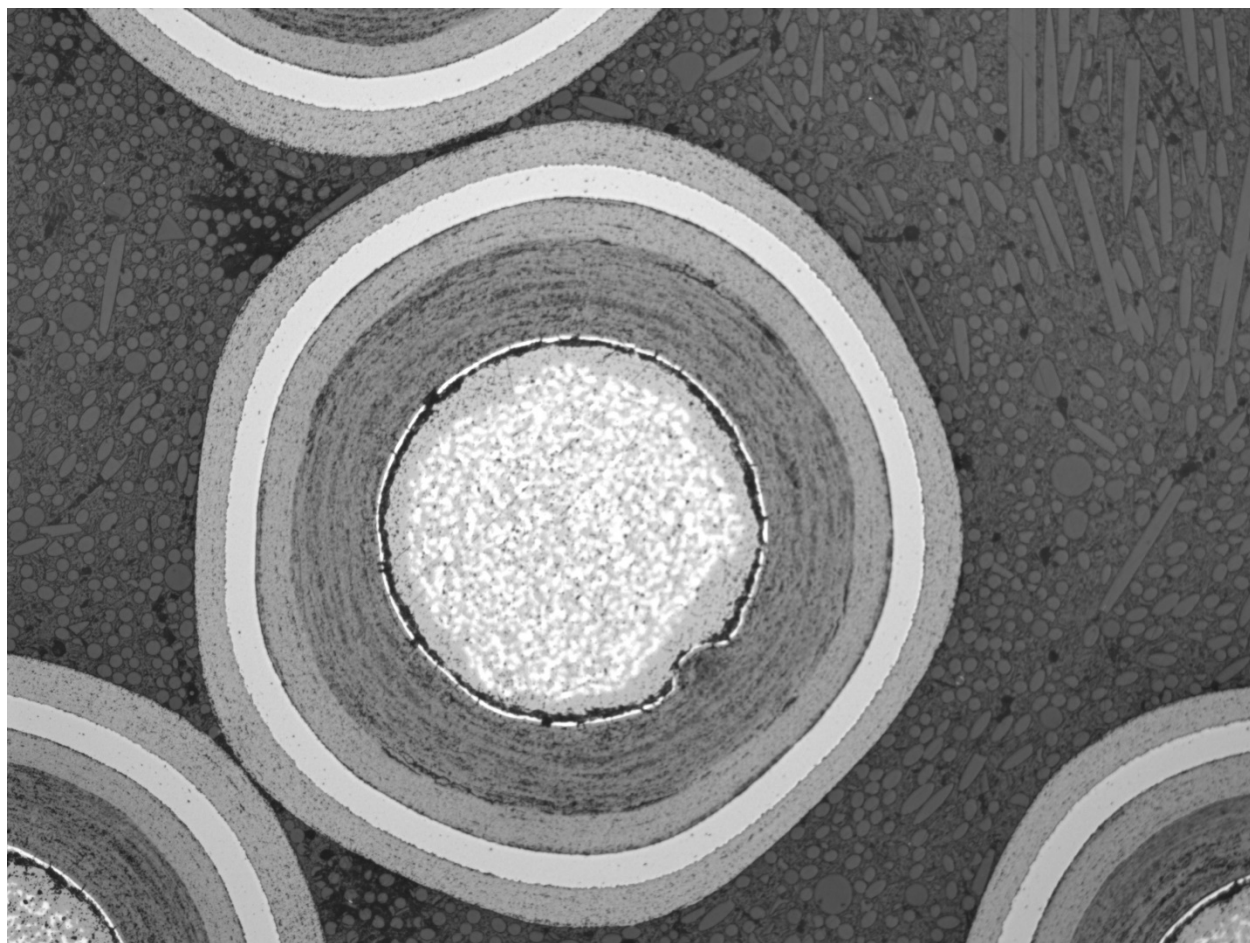


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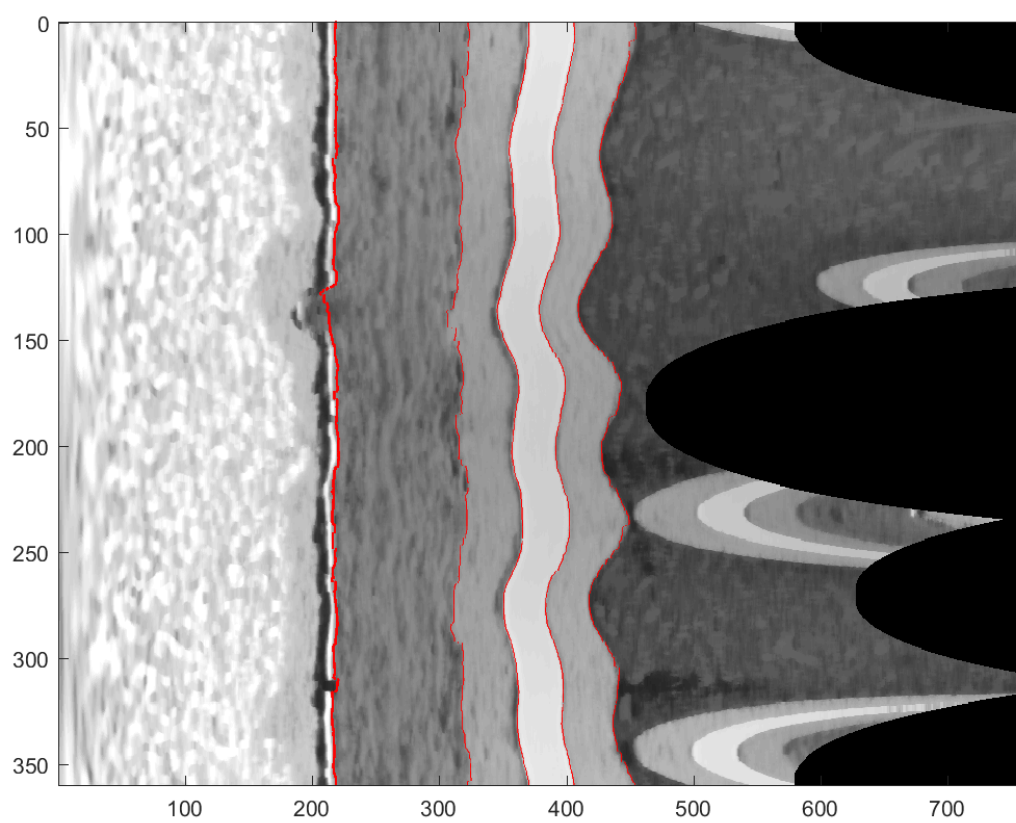


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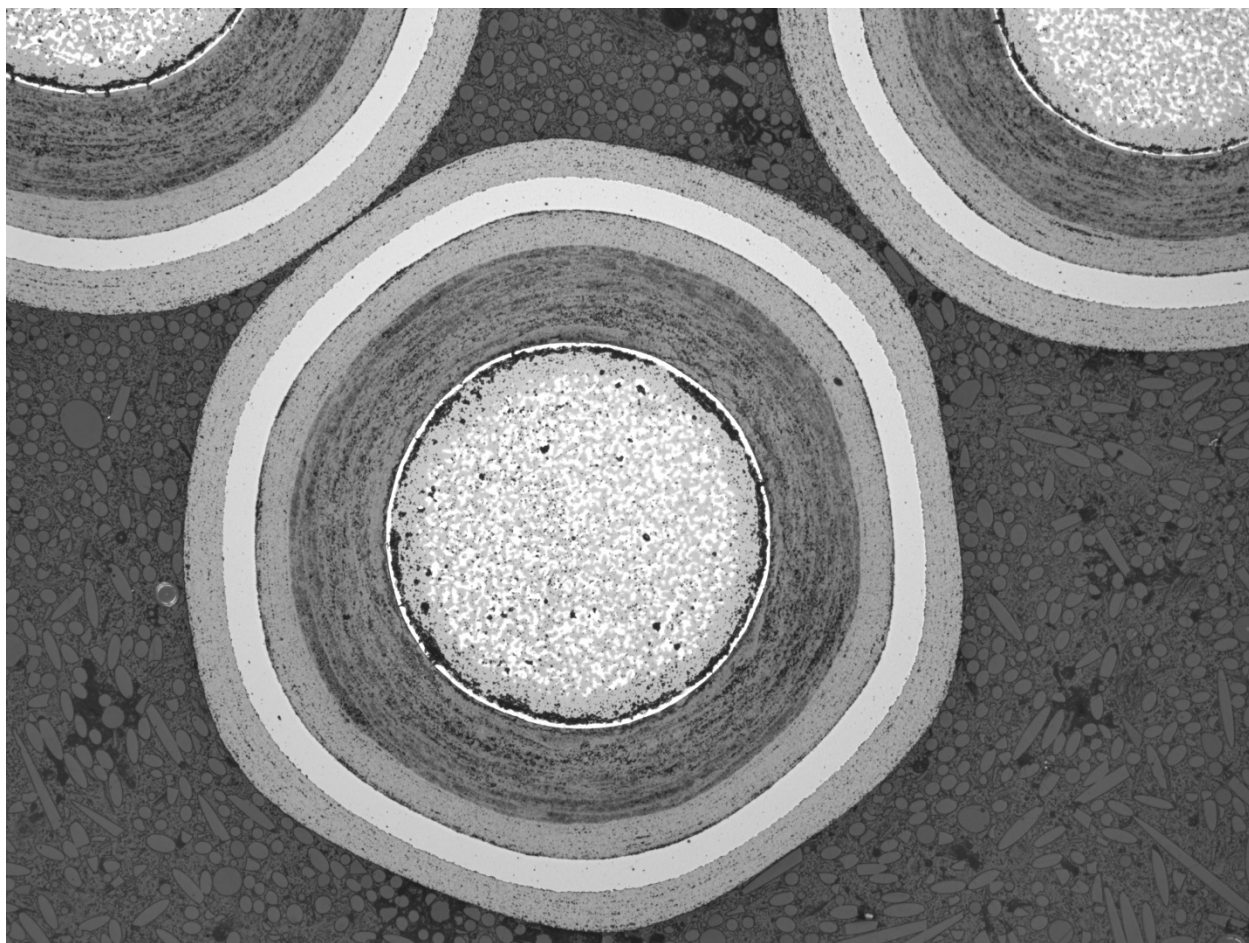


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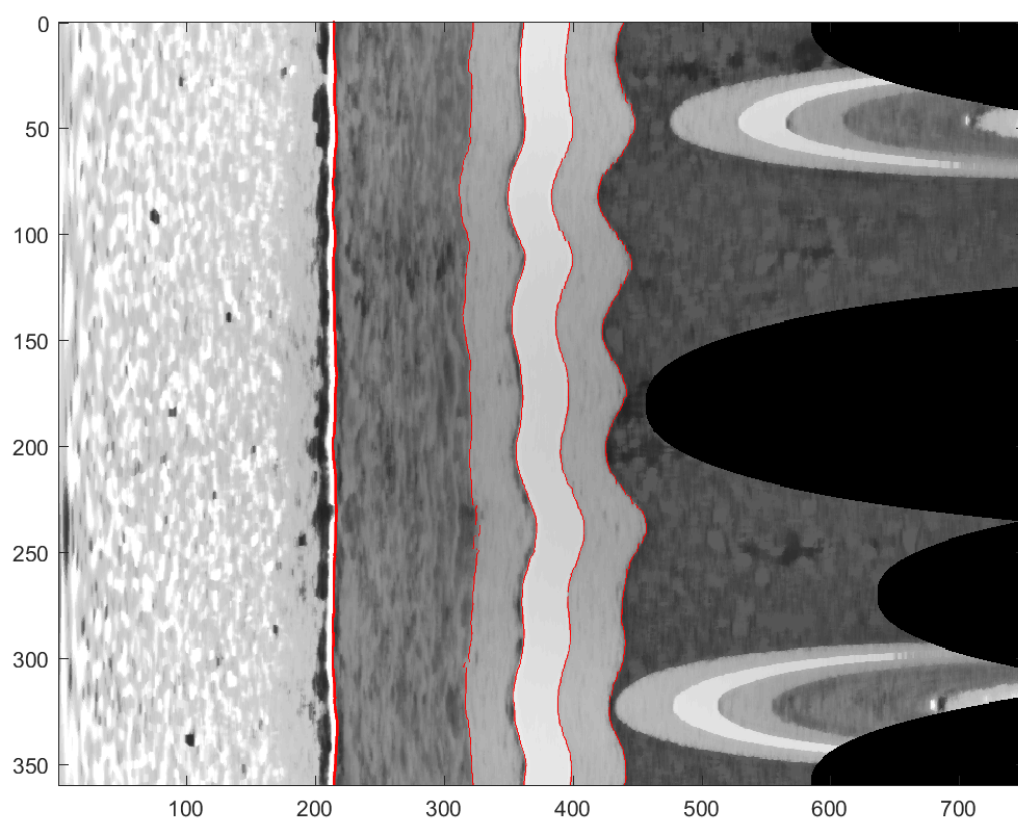


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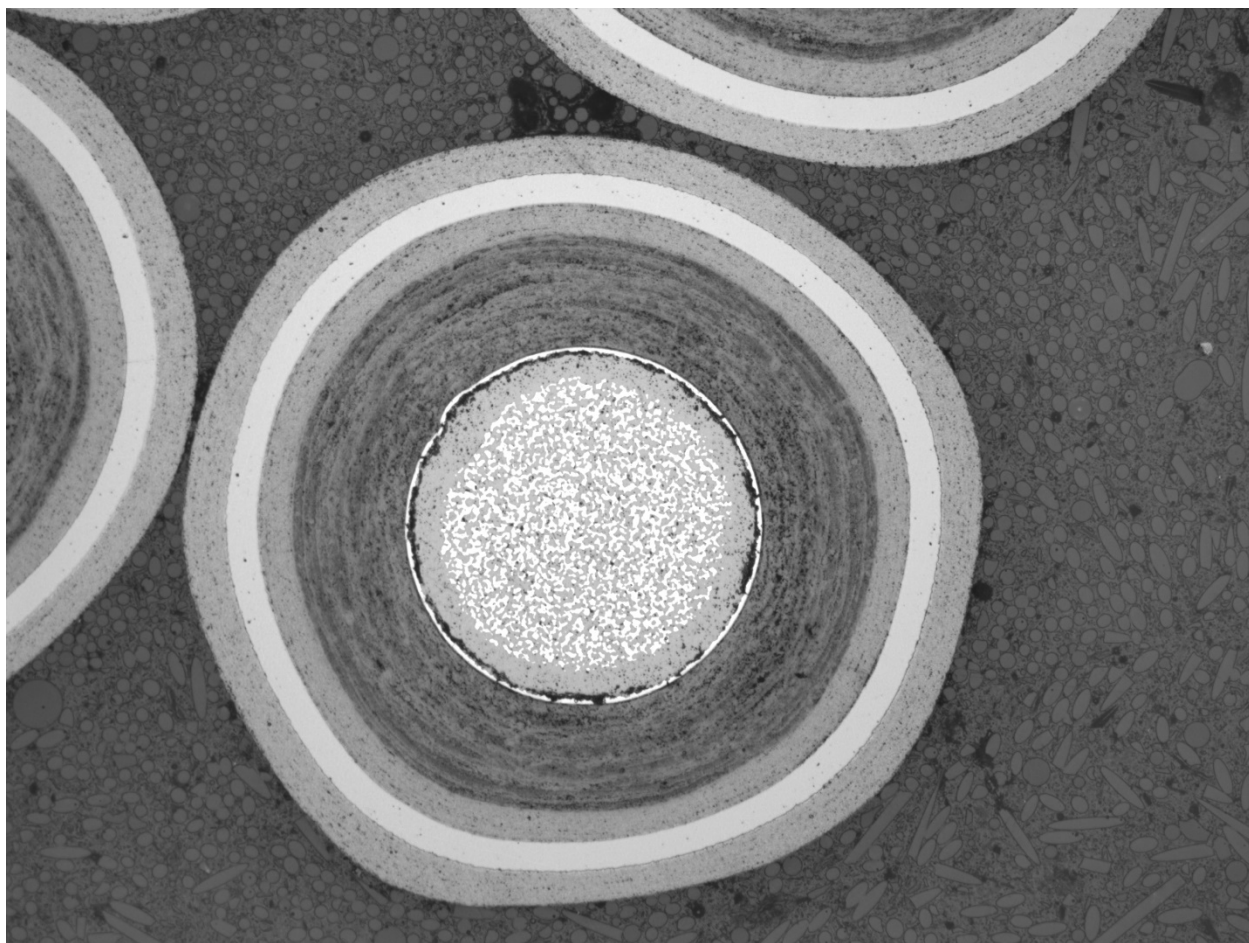




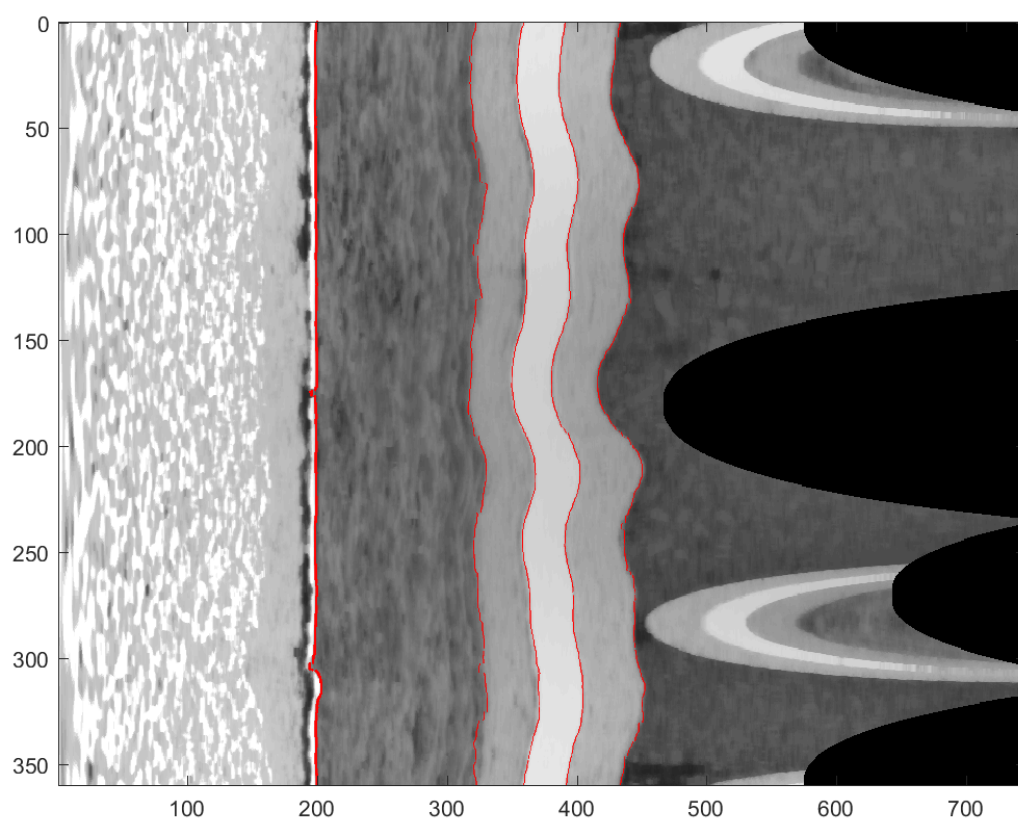
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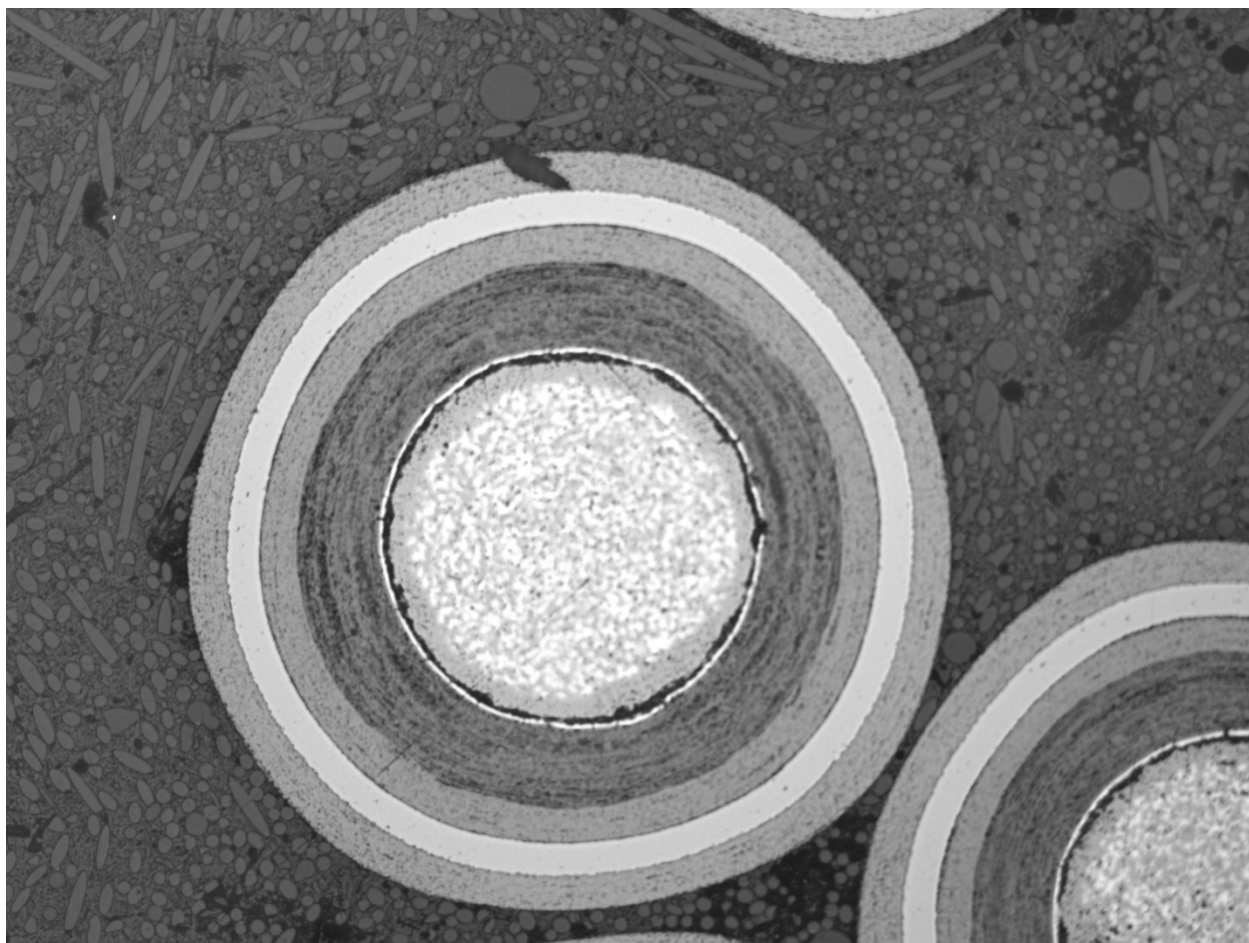
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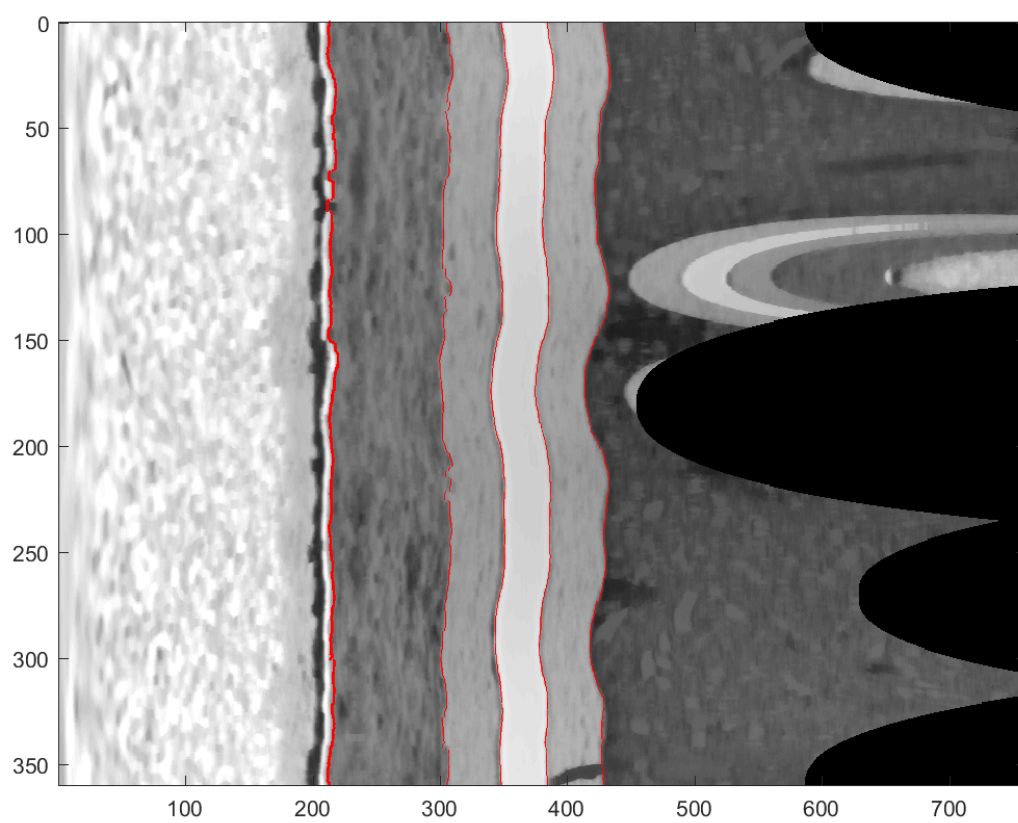
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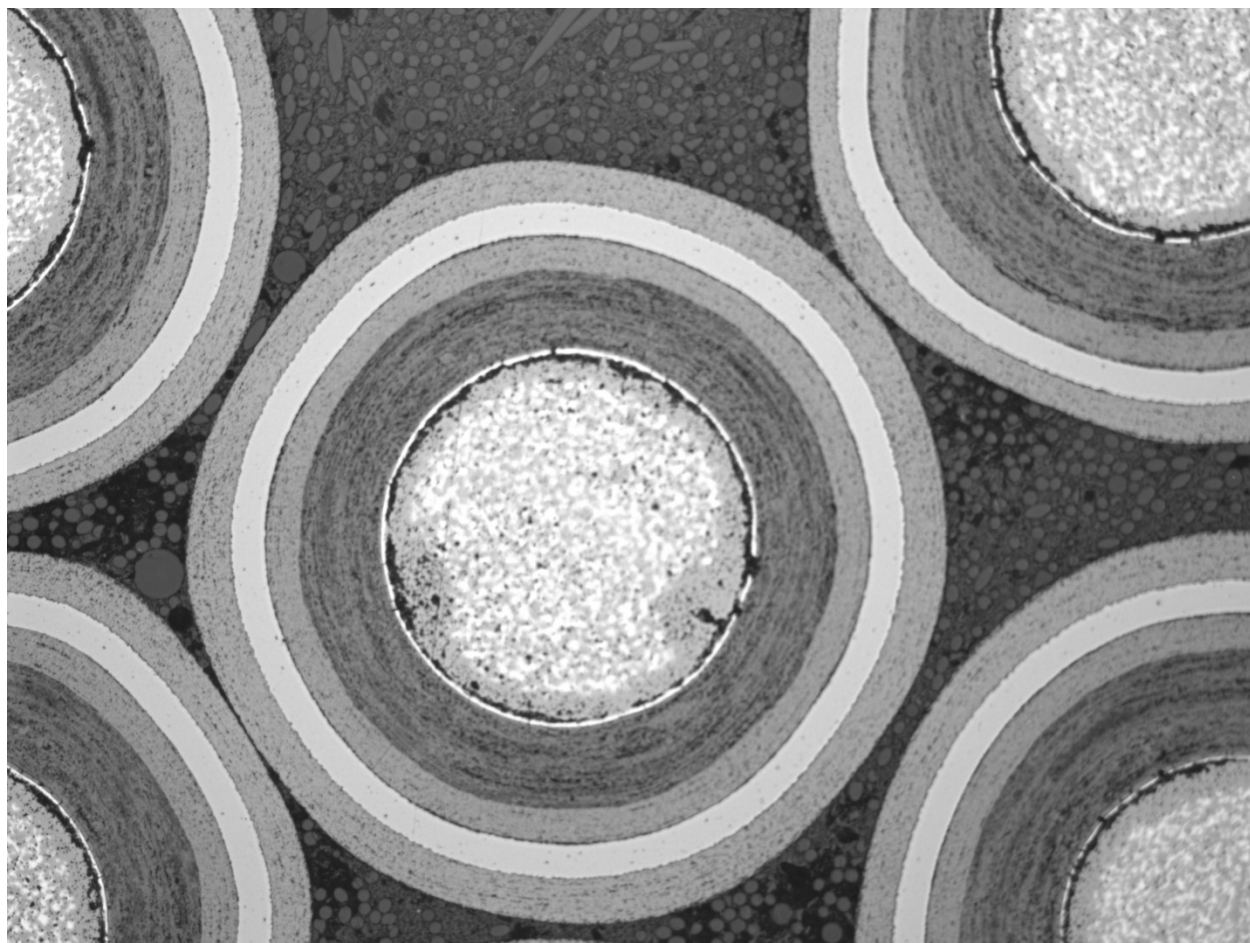
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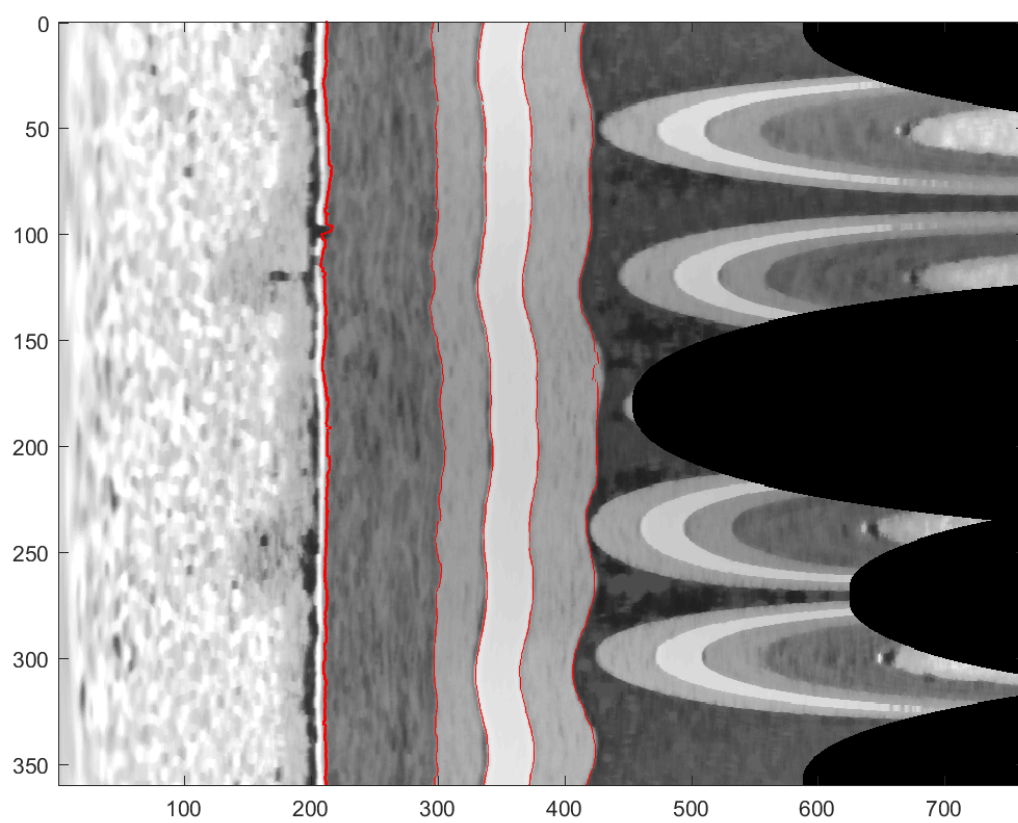


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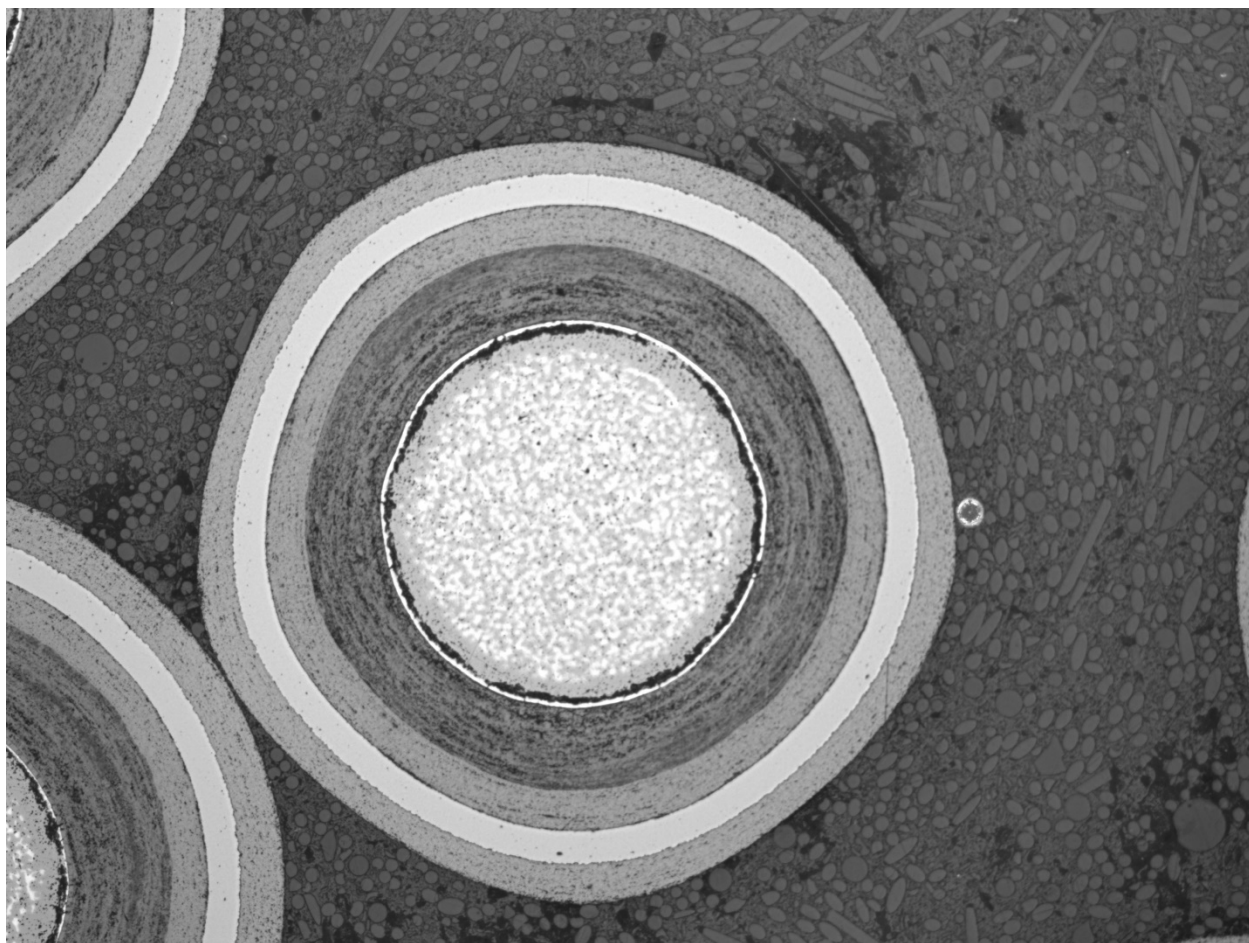
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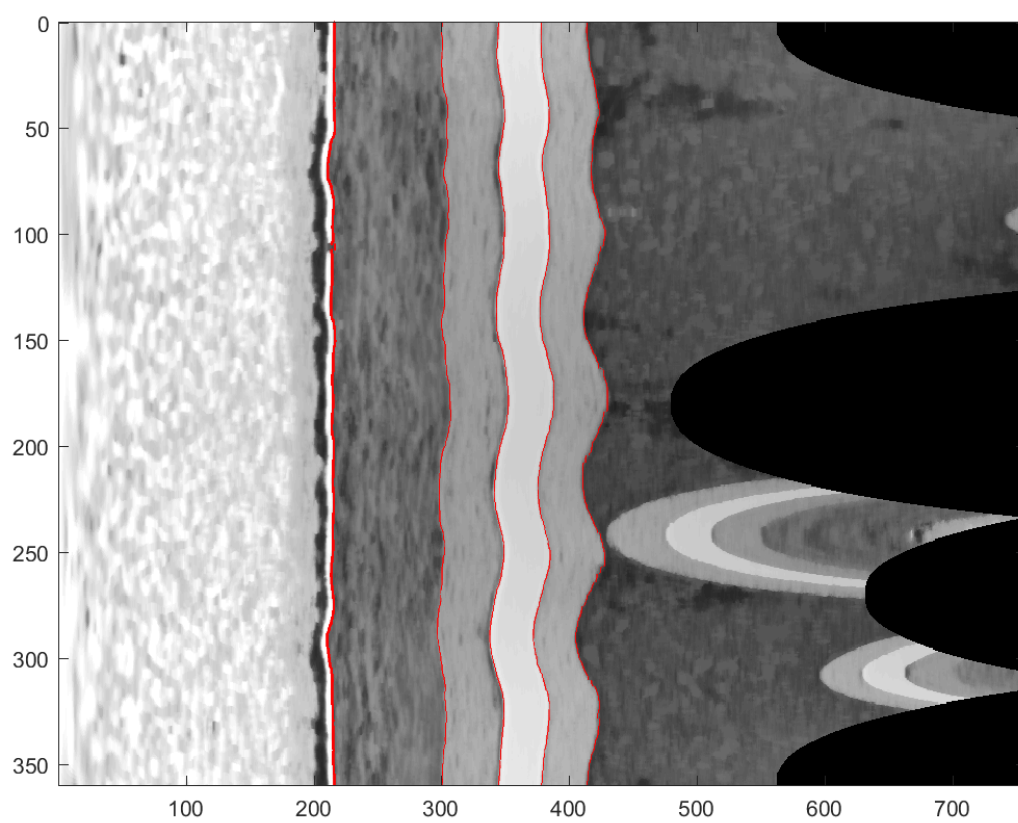


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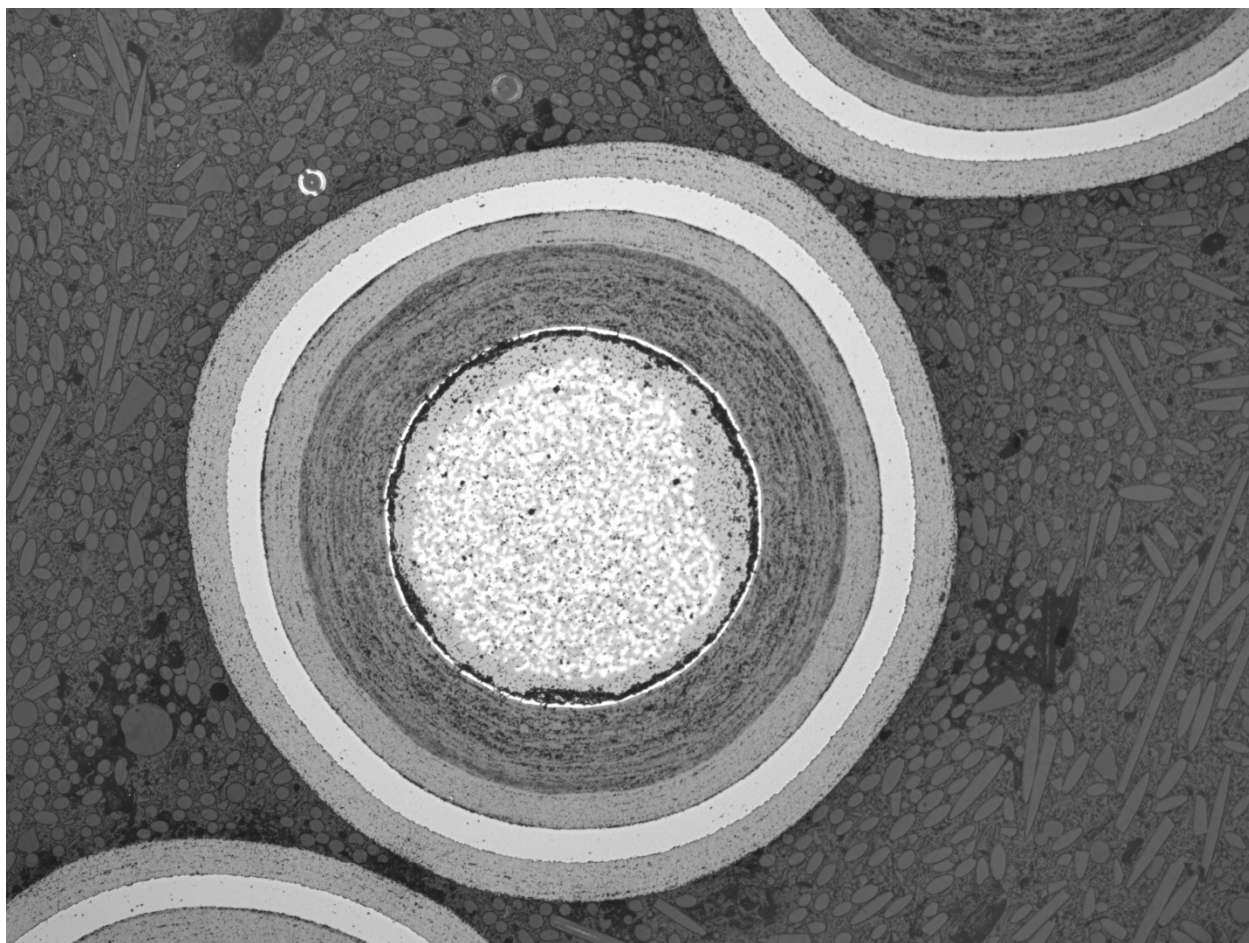




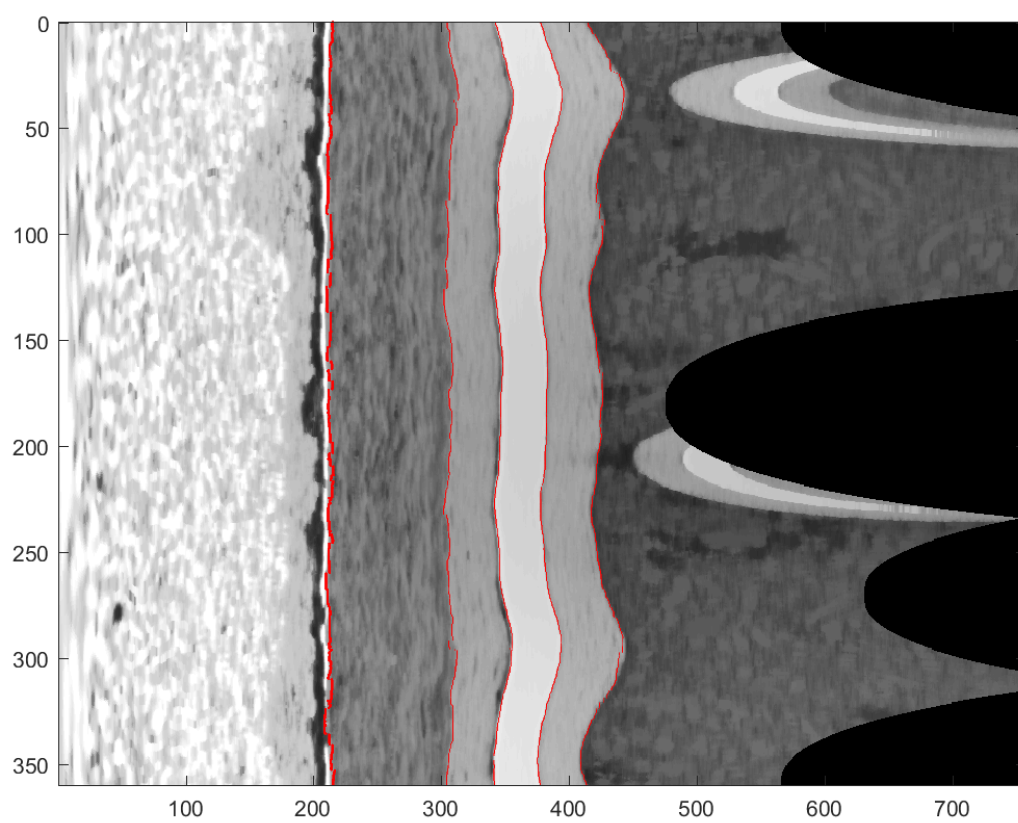
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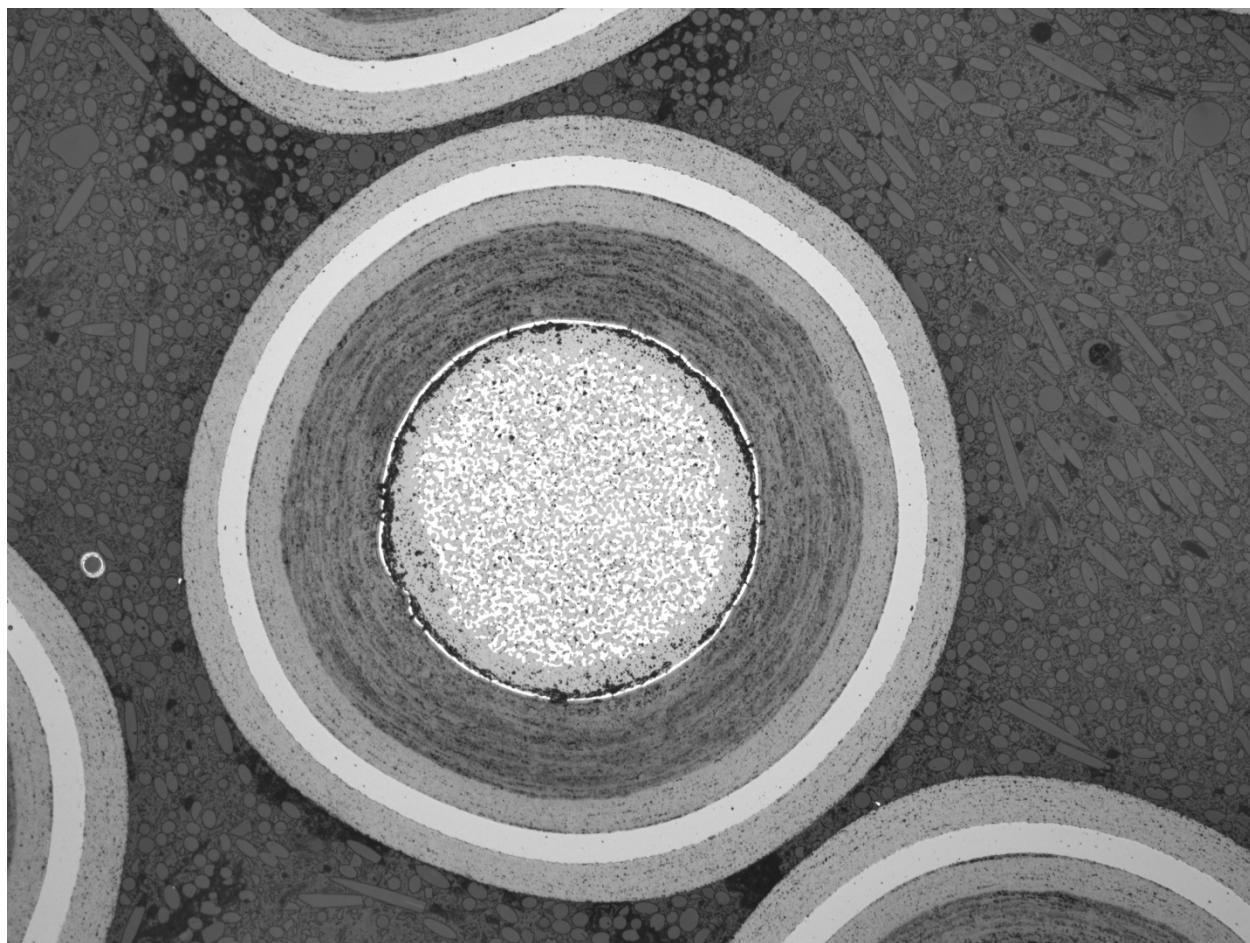
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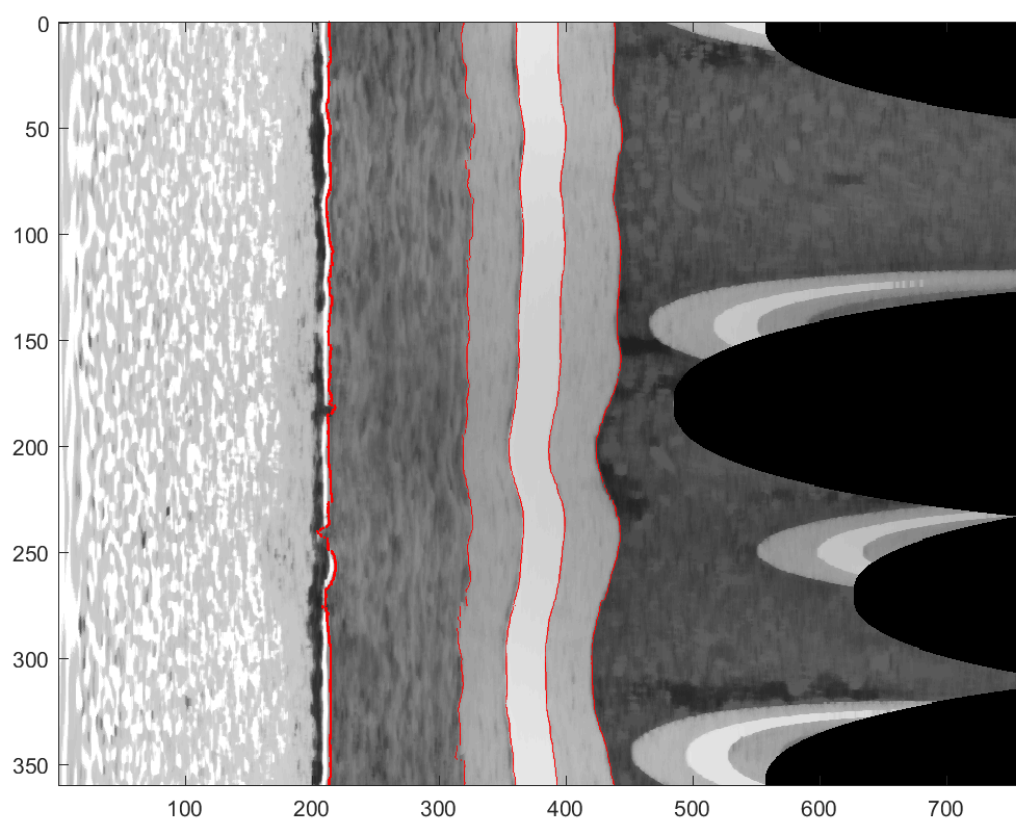
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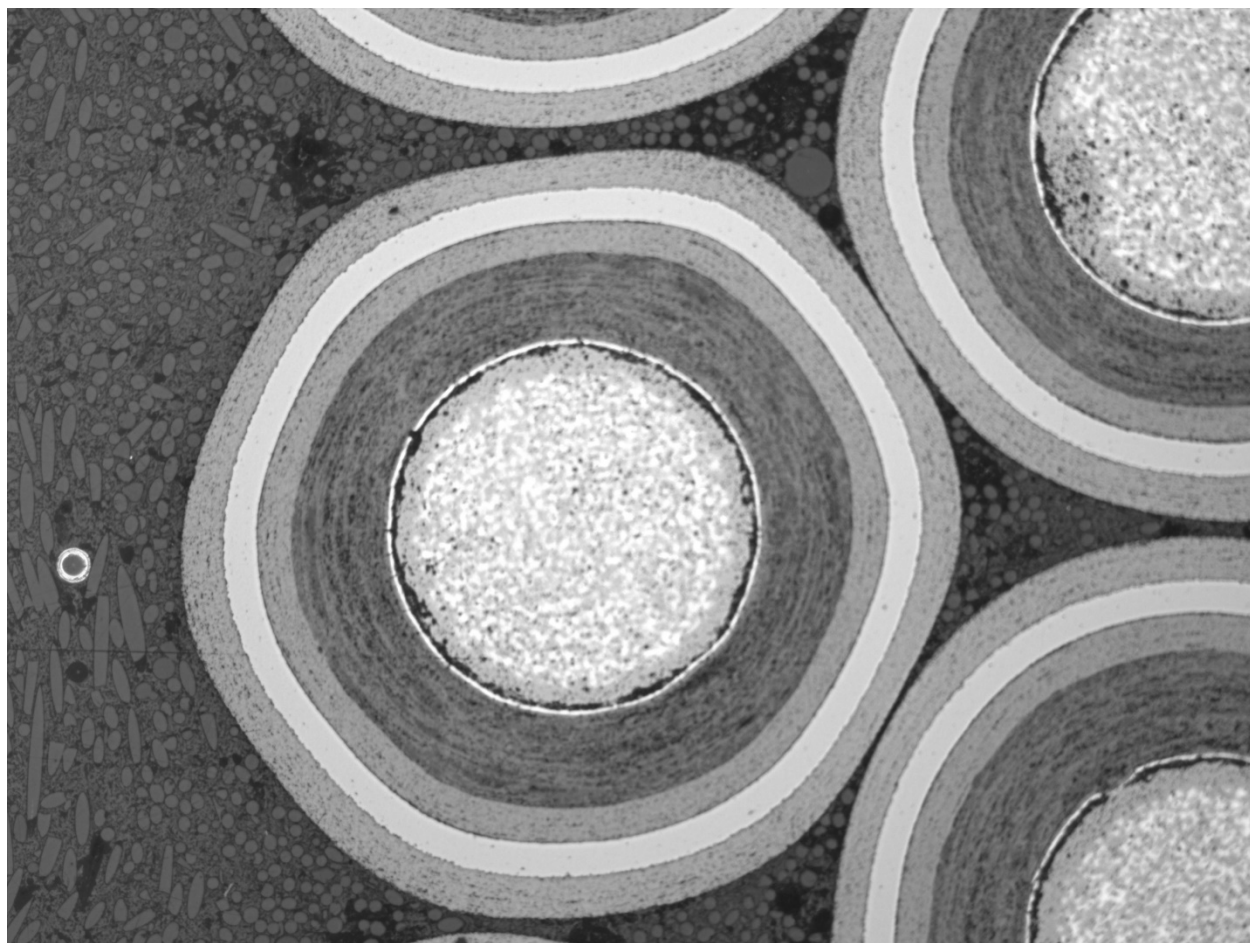
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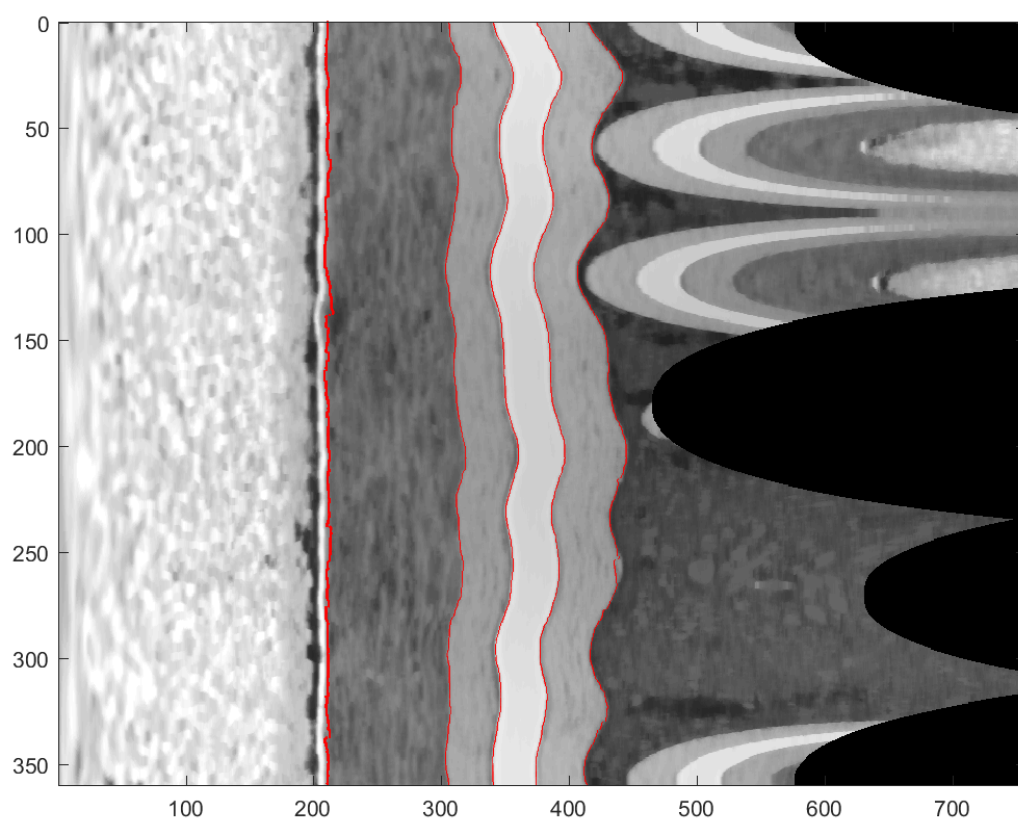


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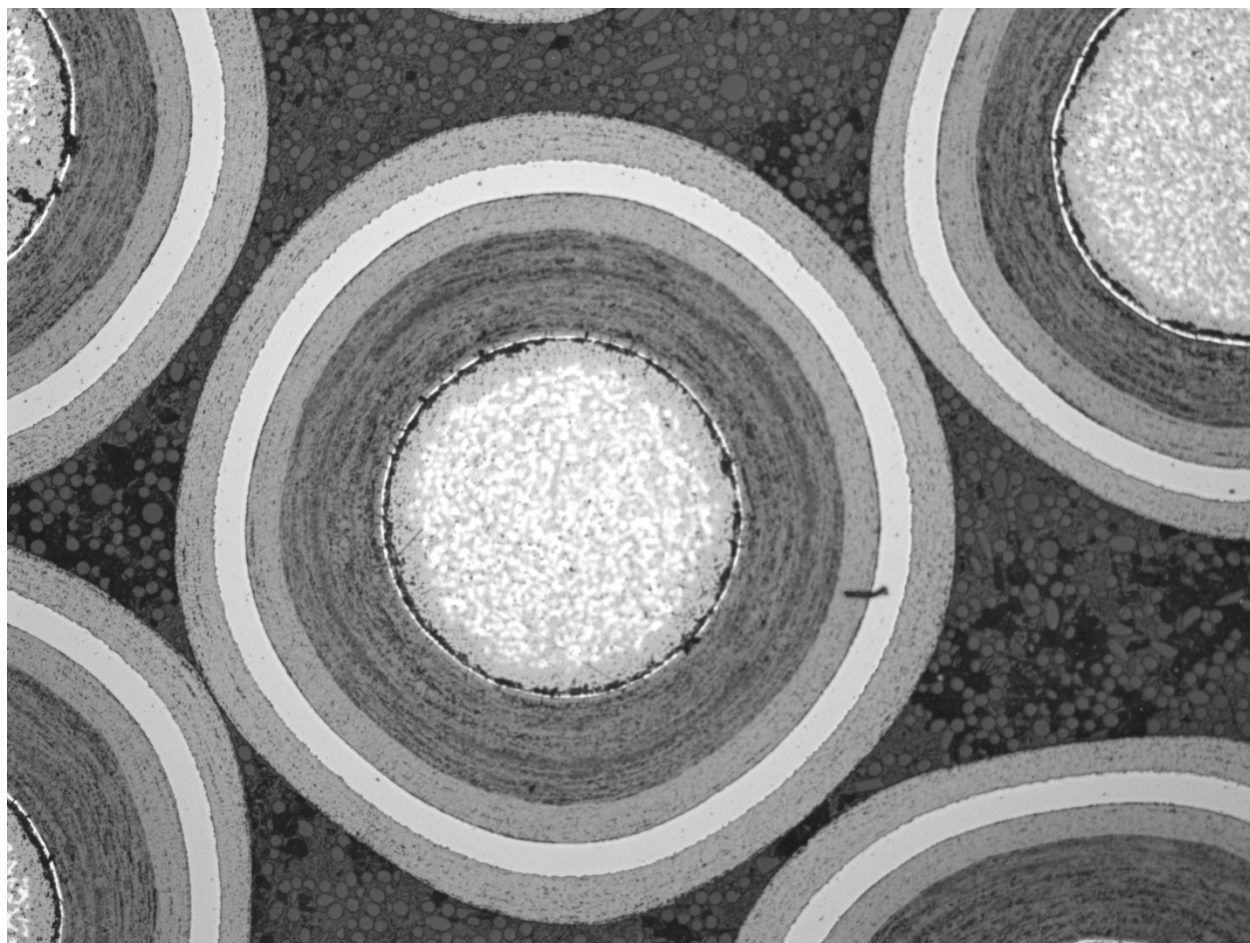
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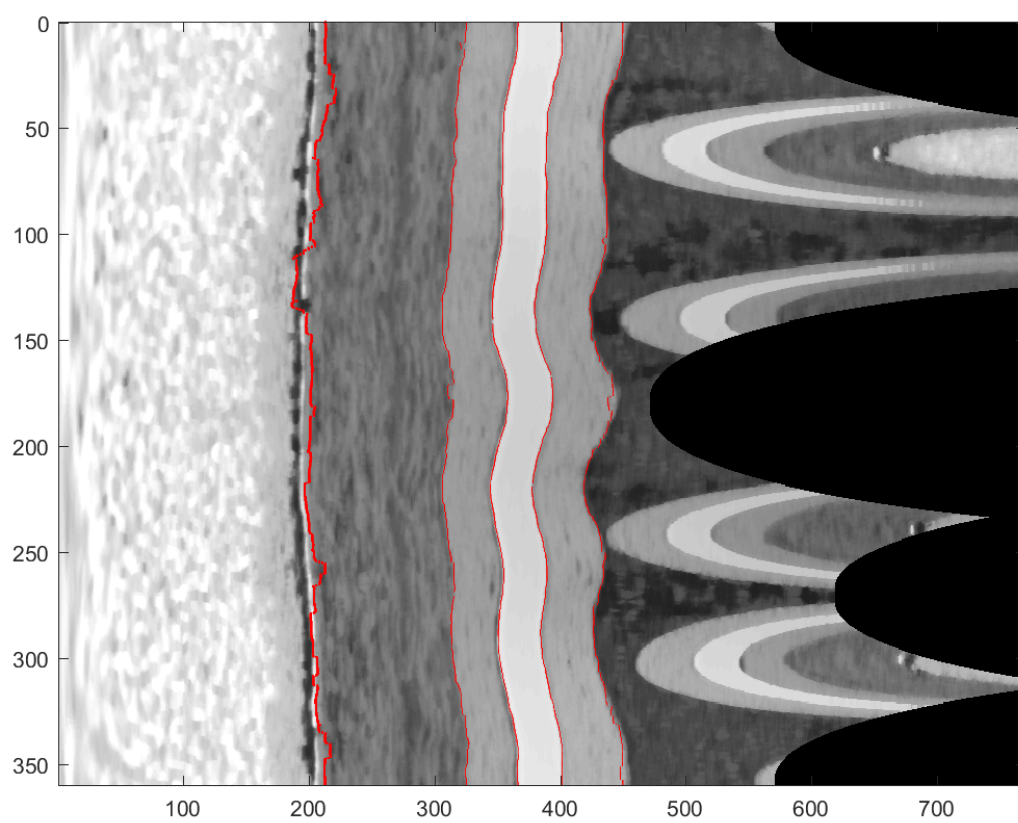


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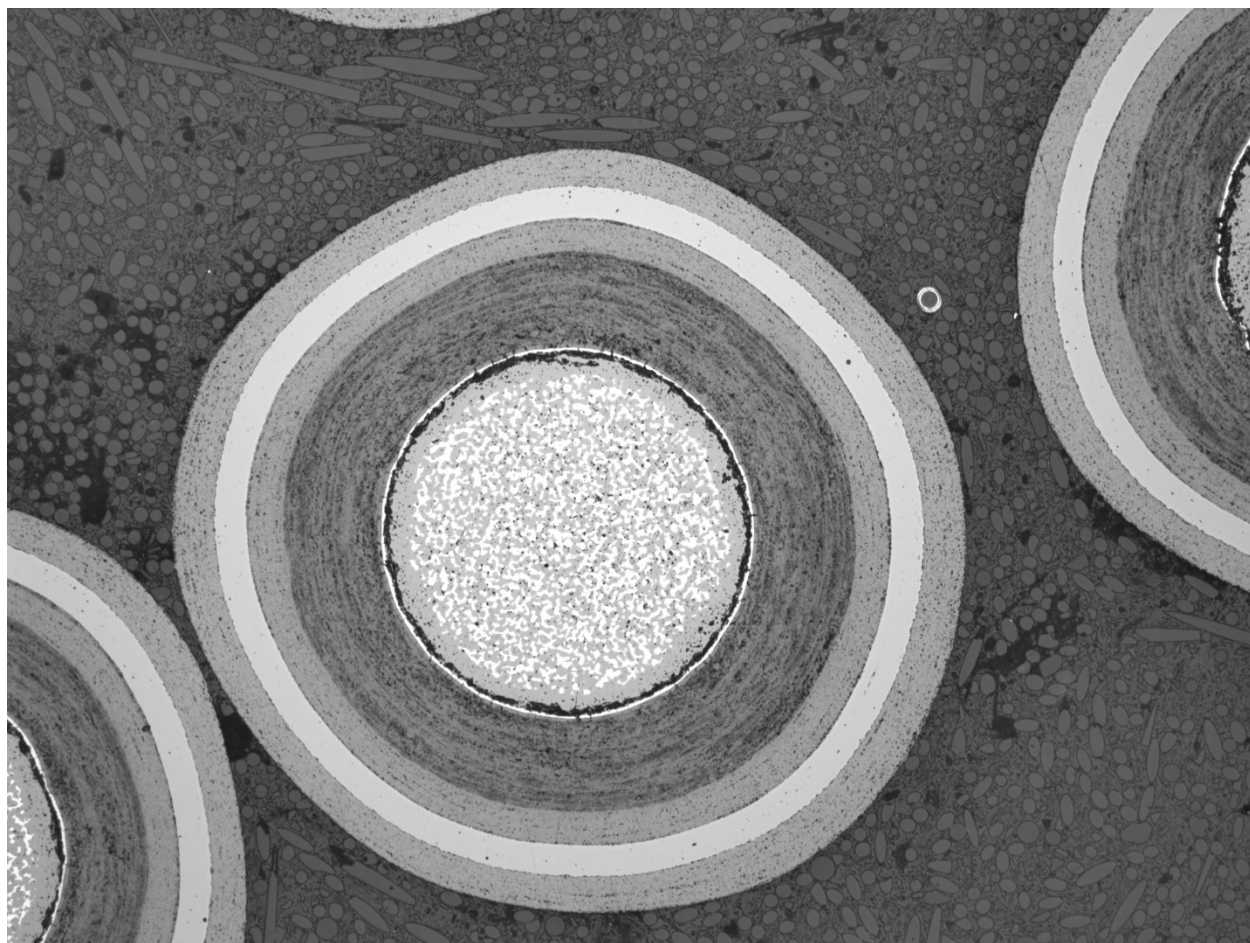




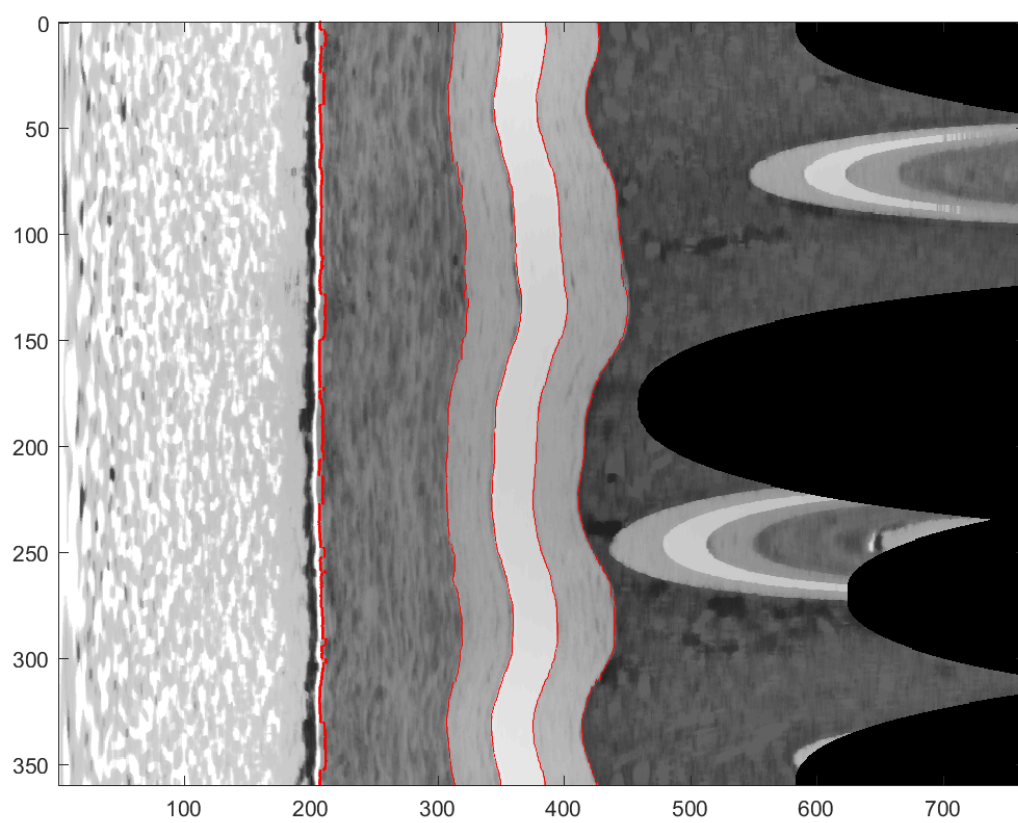
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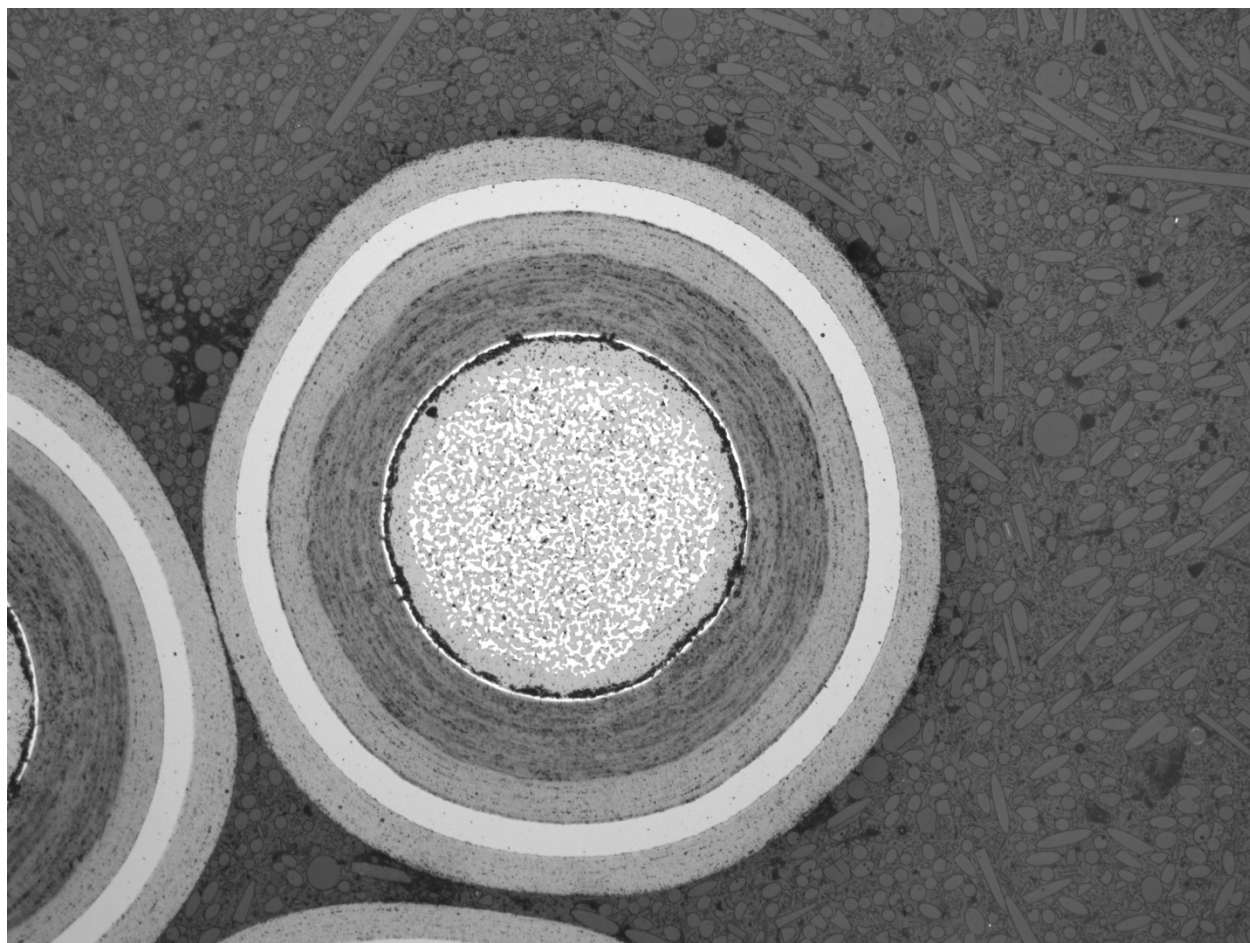
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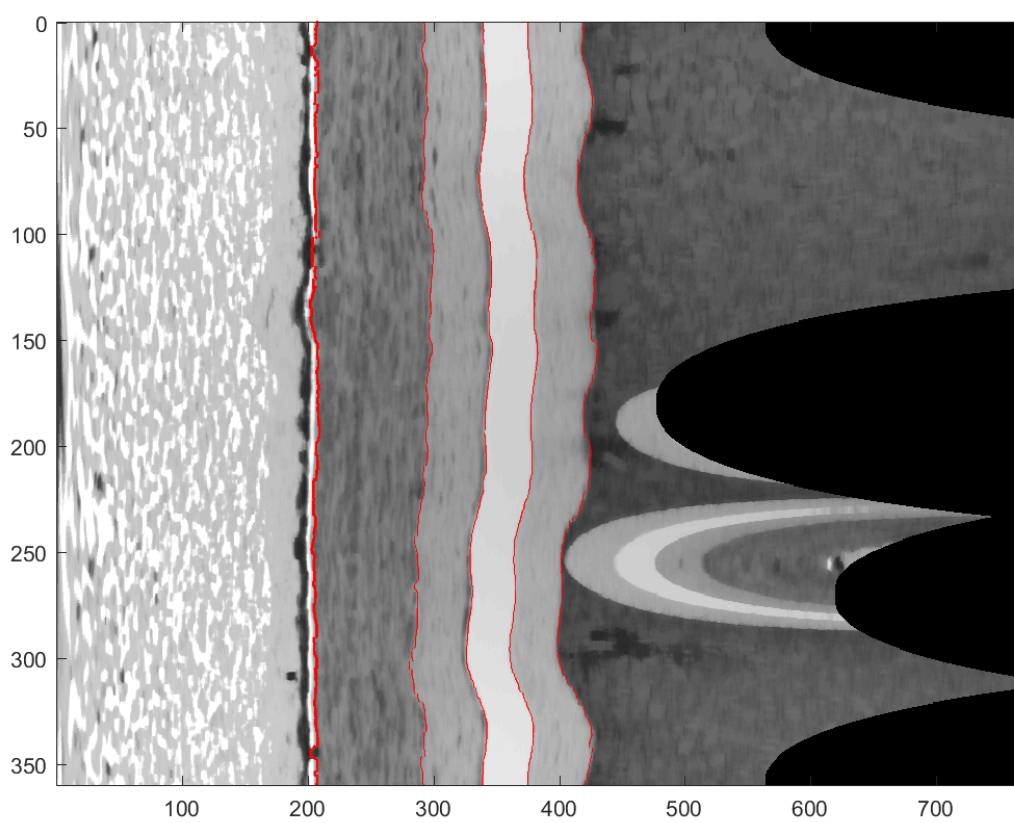
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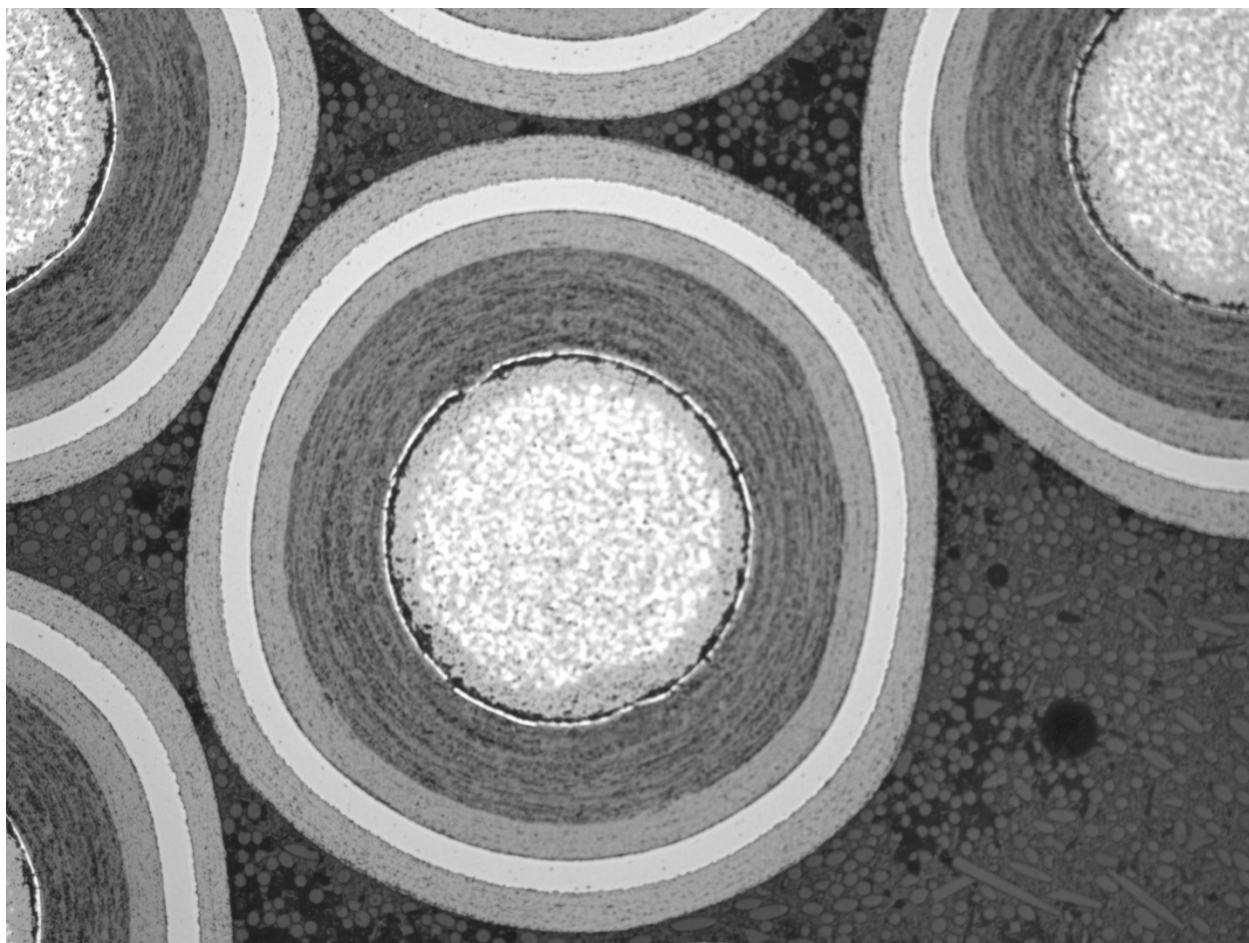
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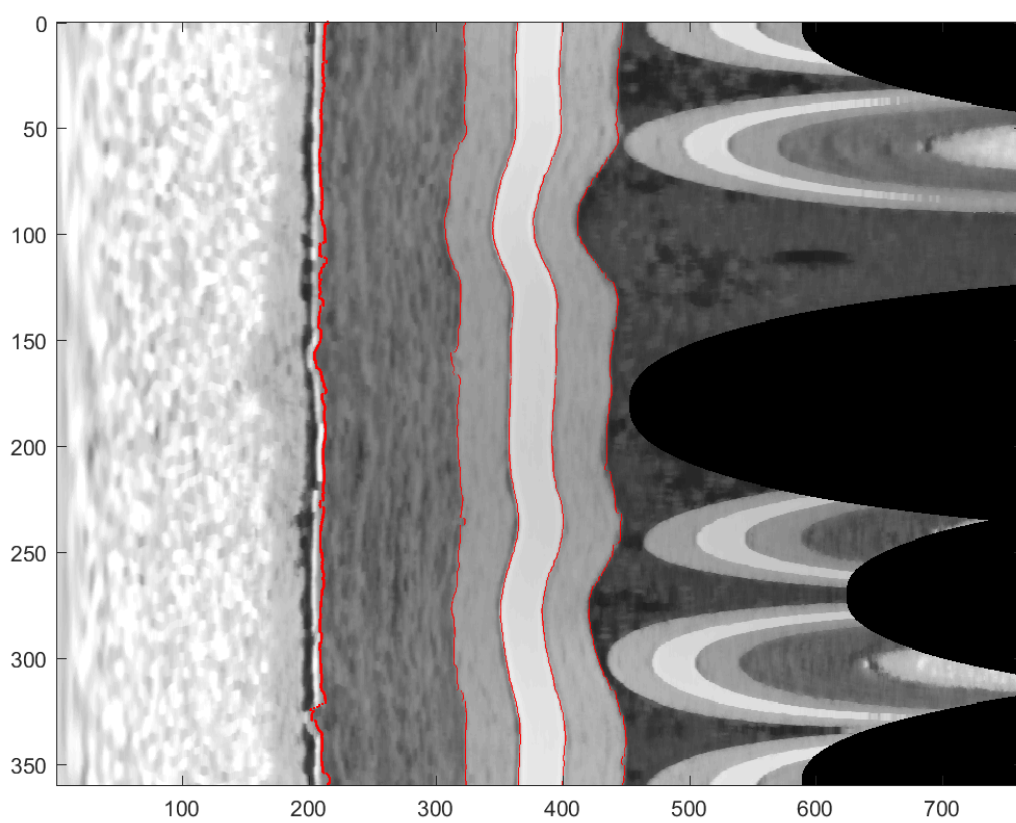


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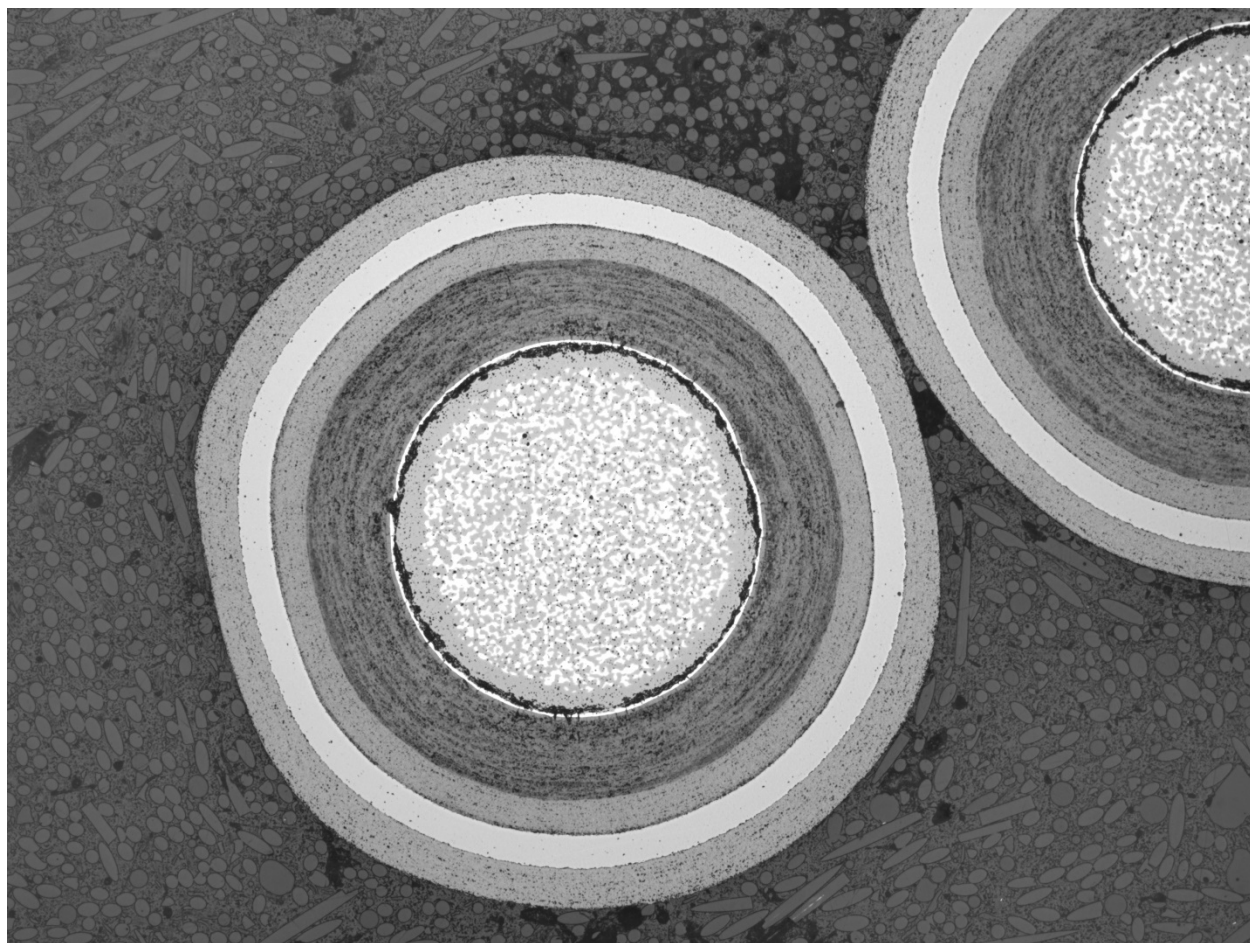
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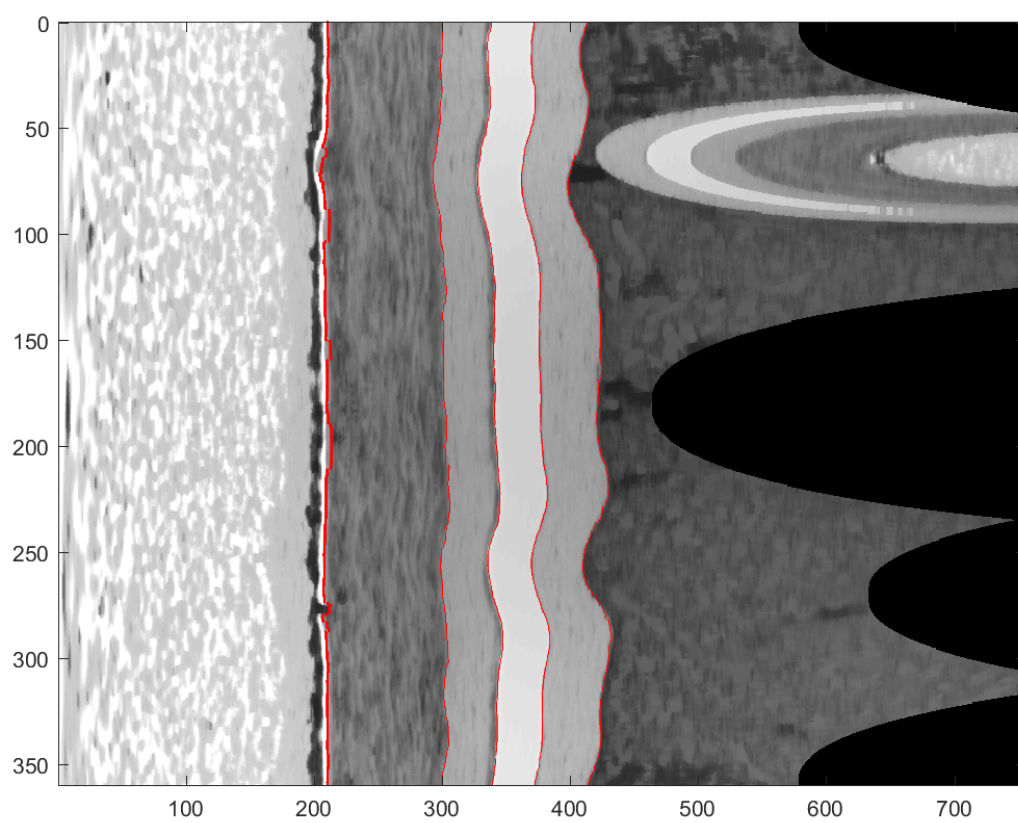


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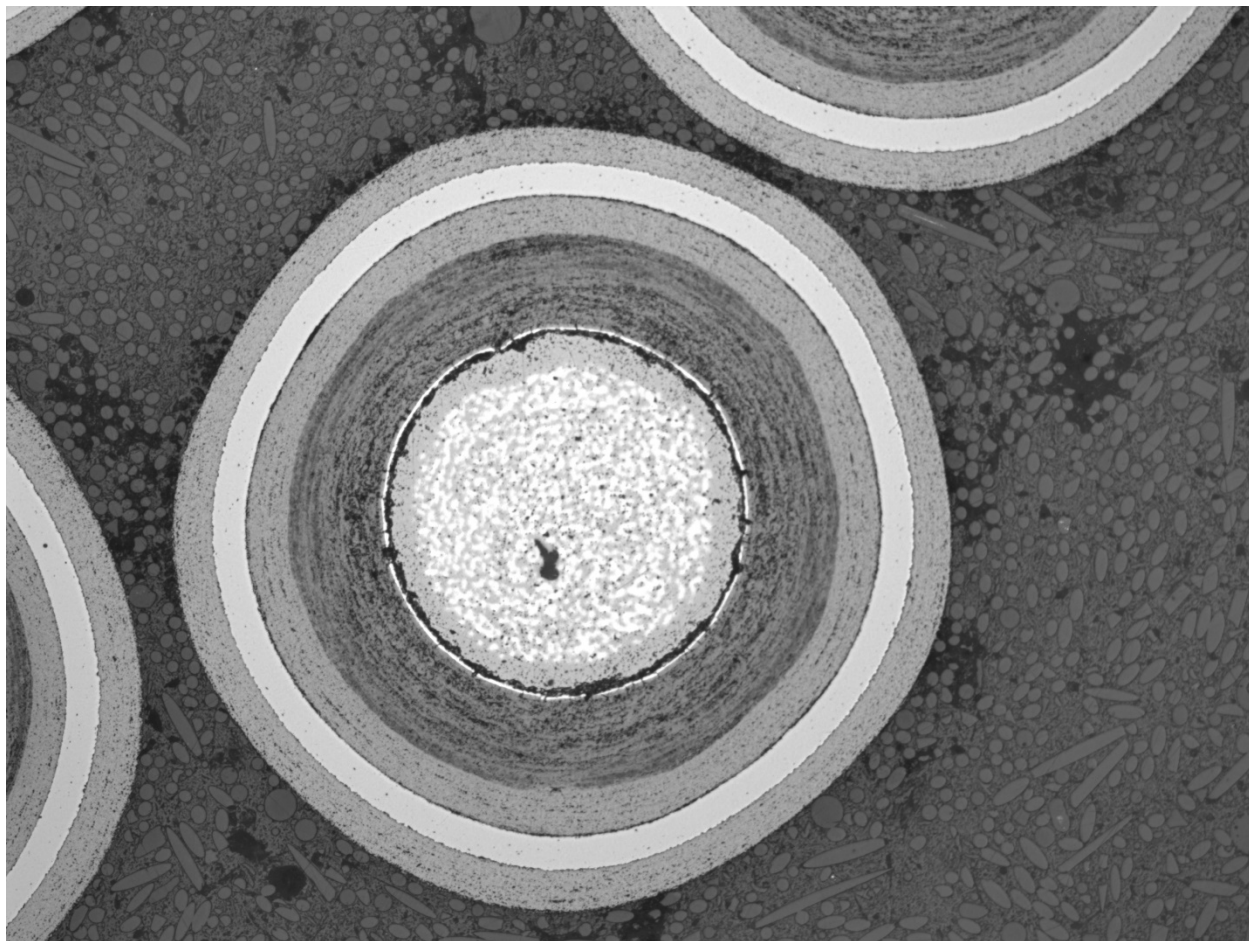




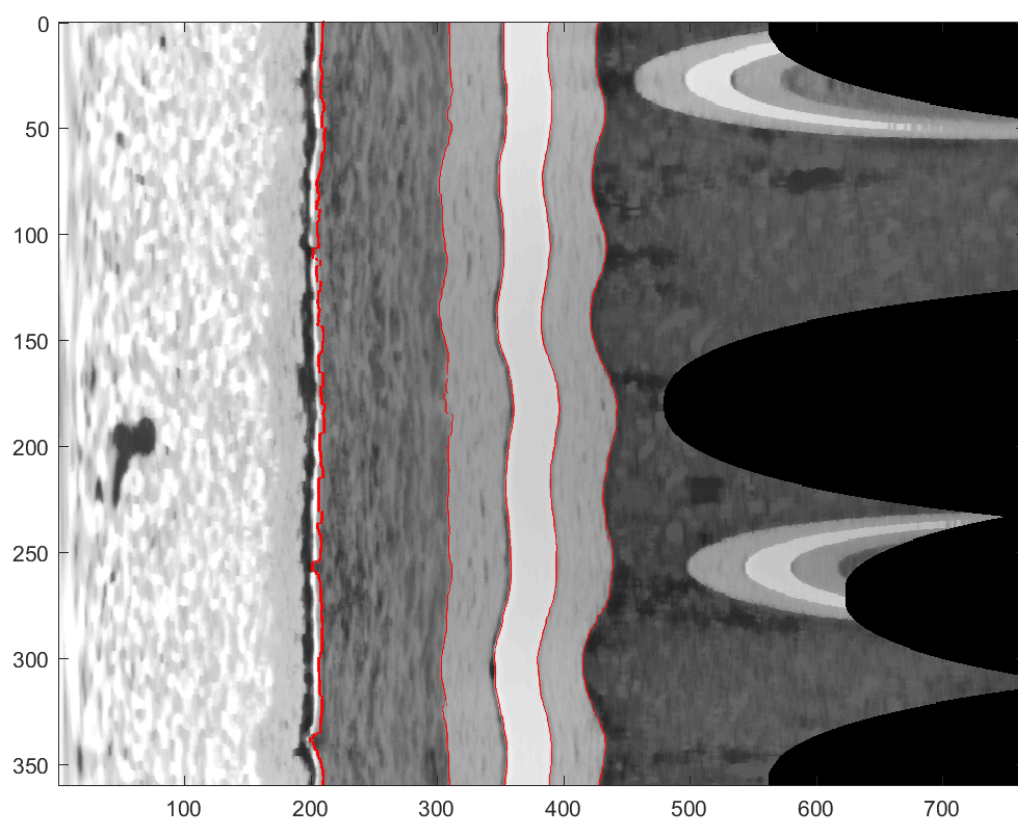
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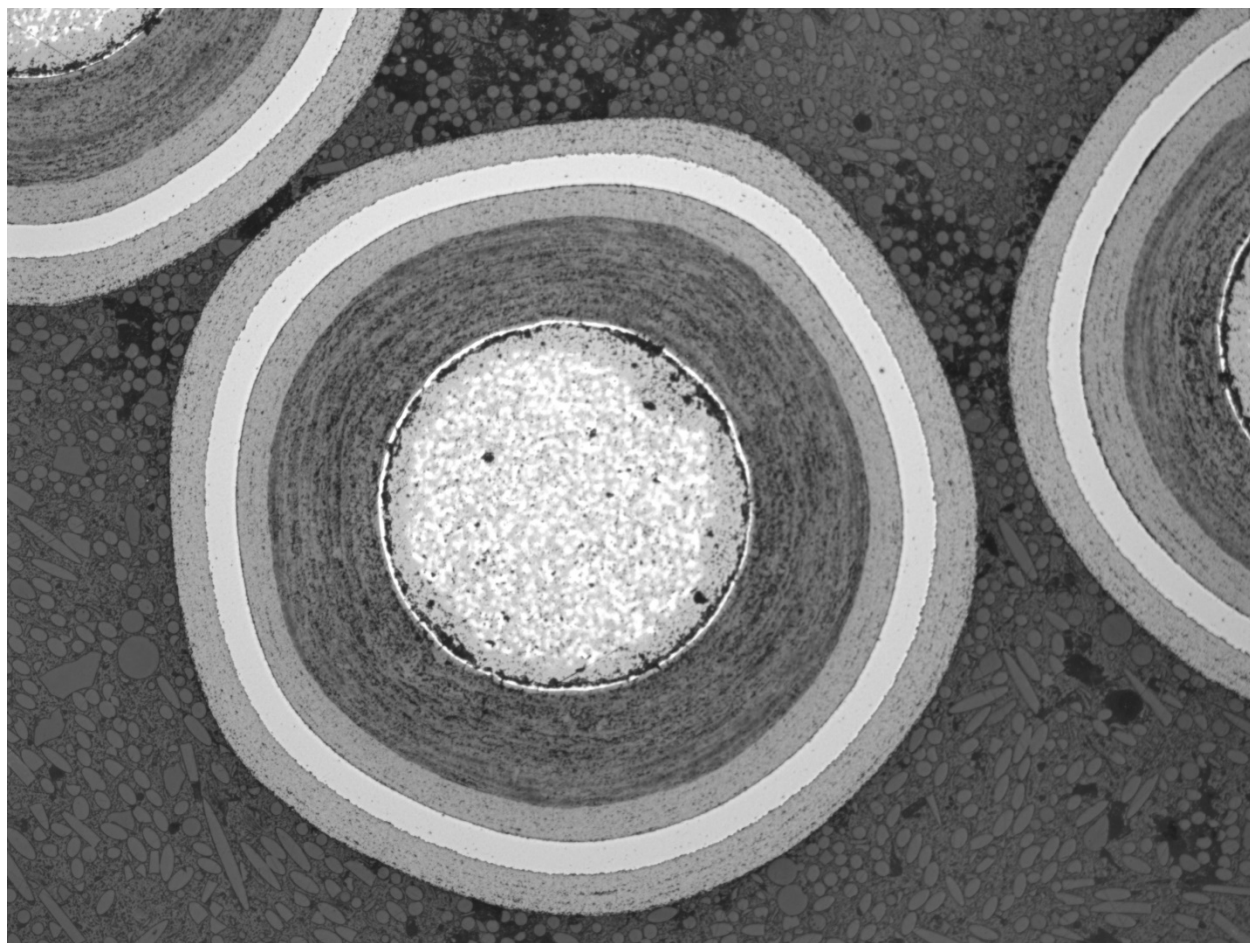
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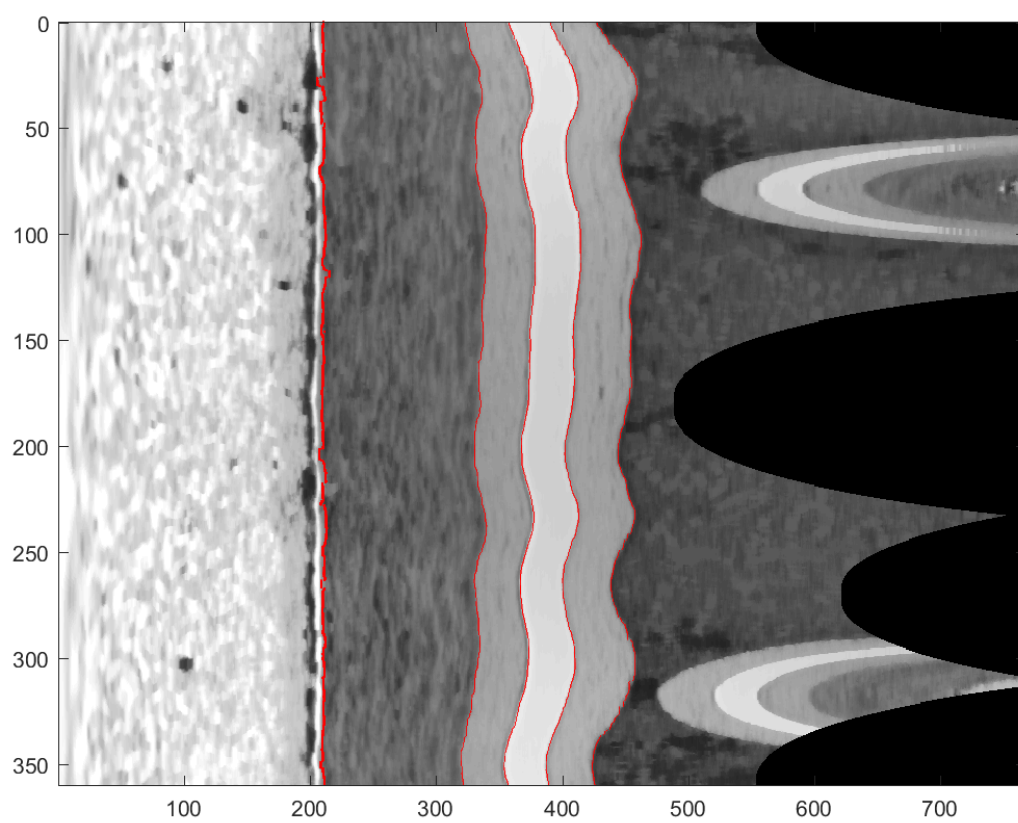
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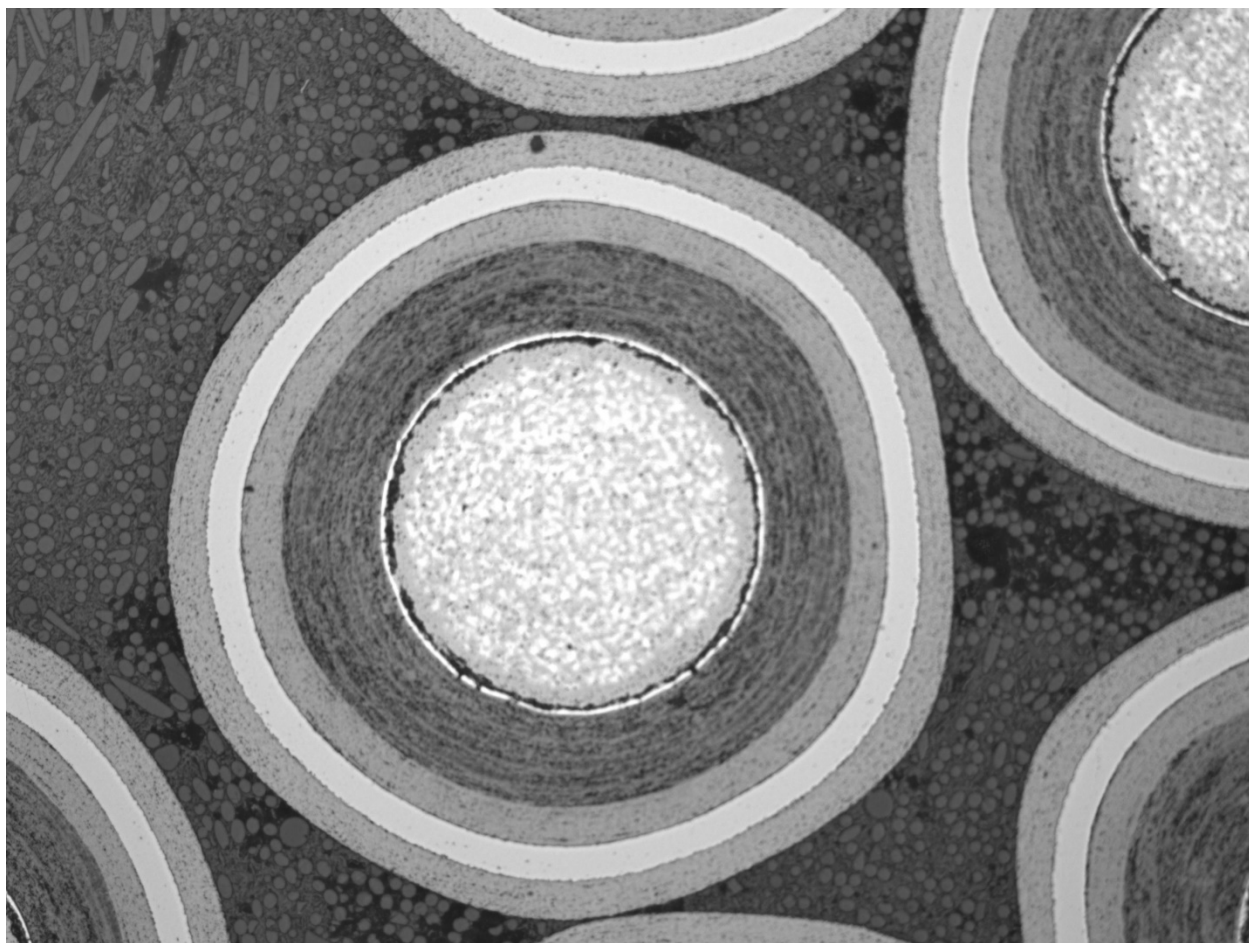
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P16070801N049

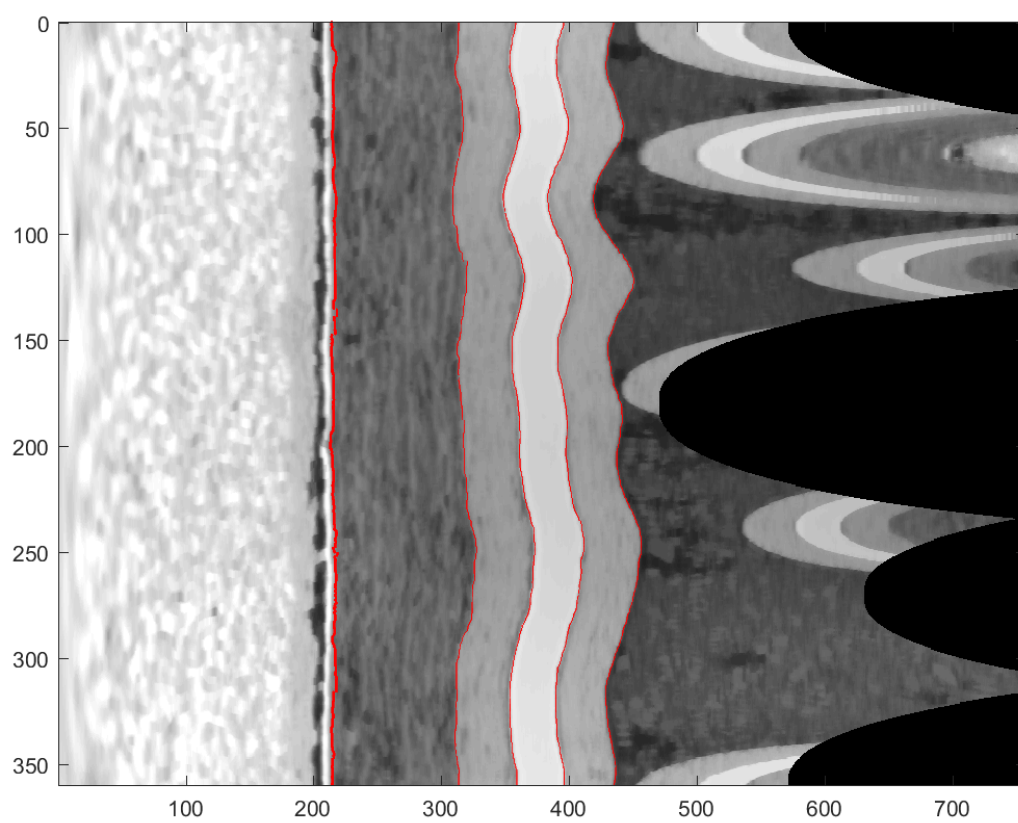


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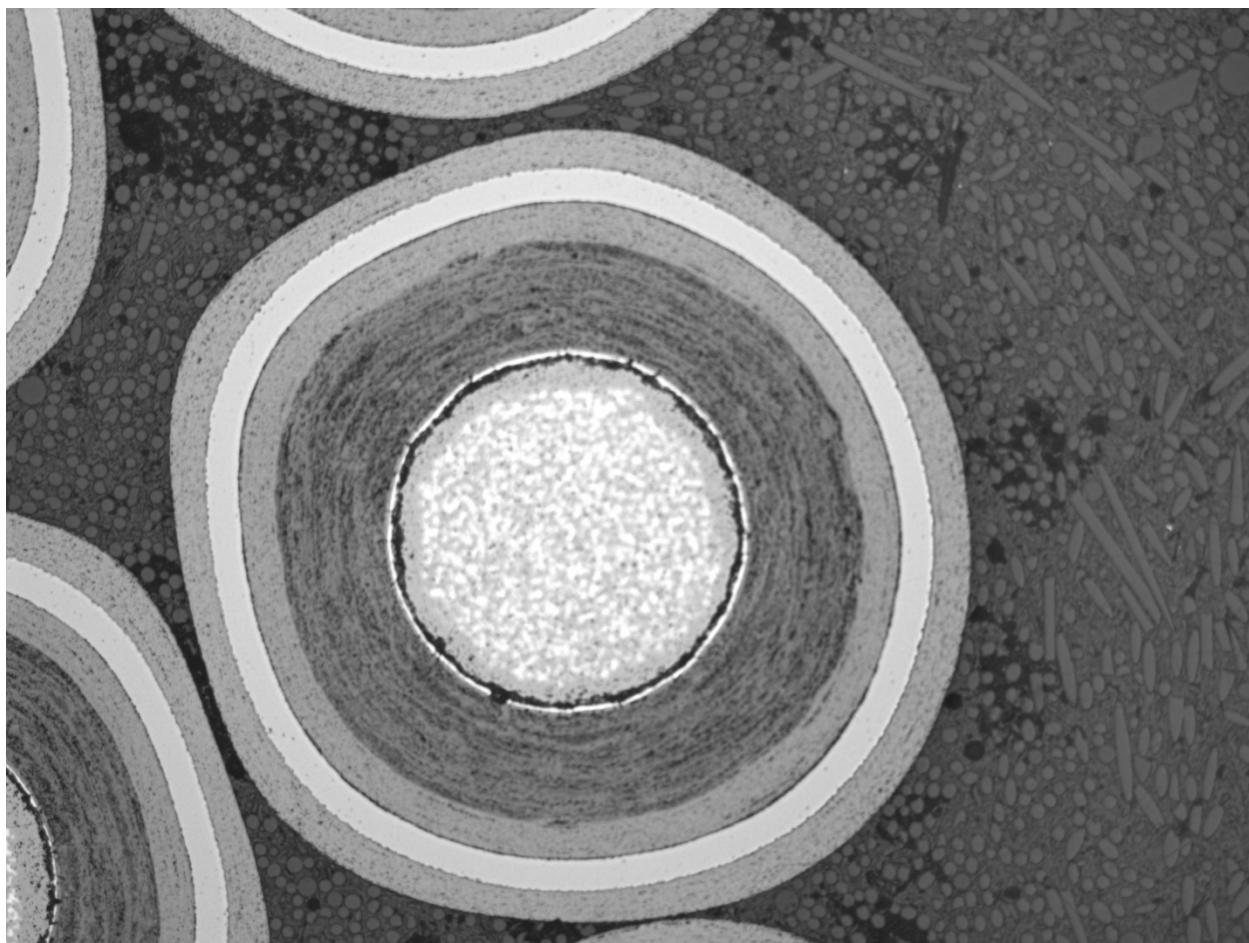


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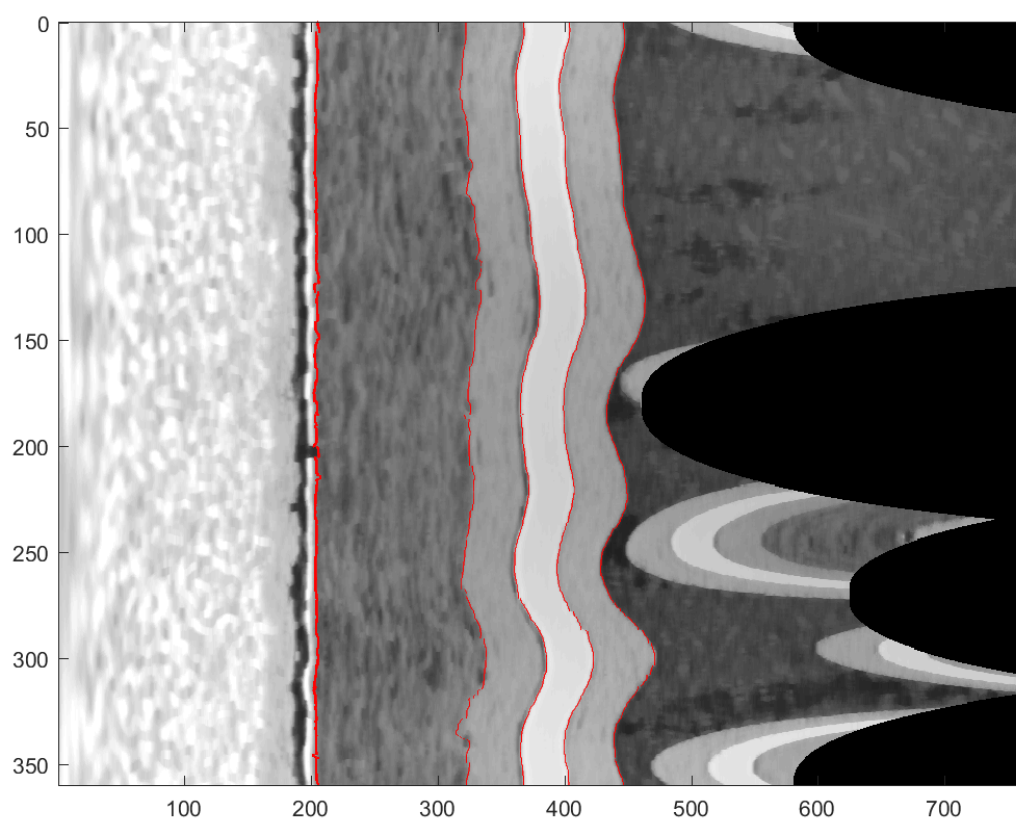




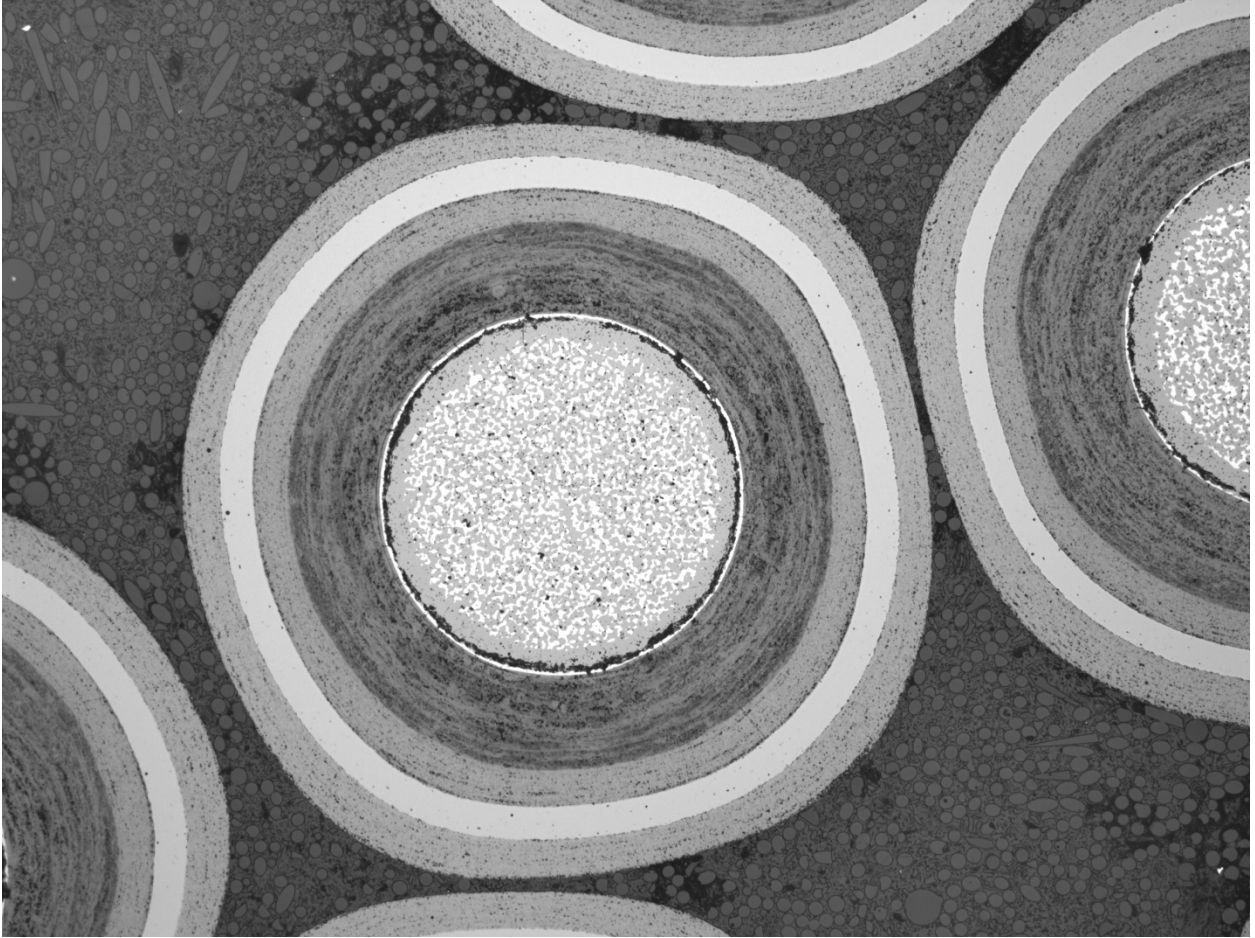
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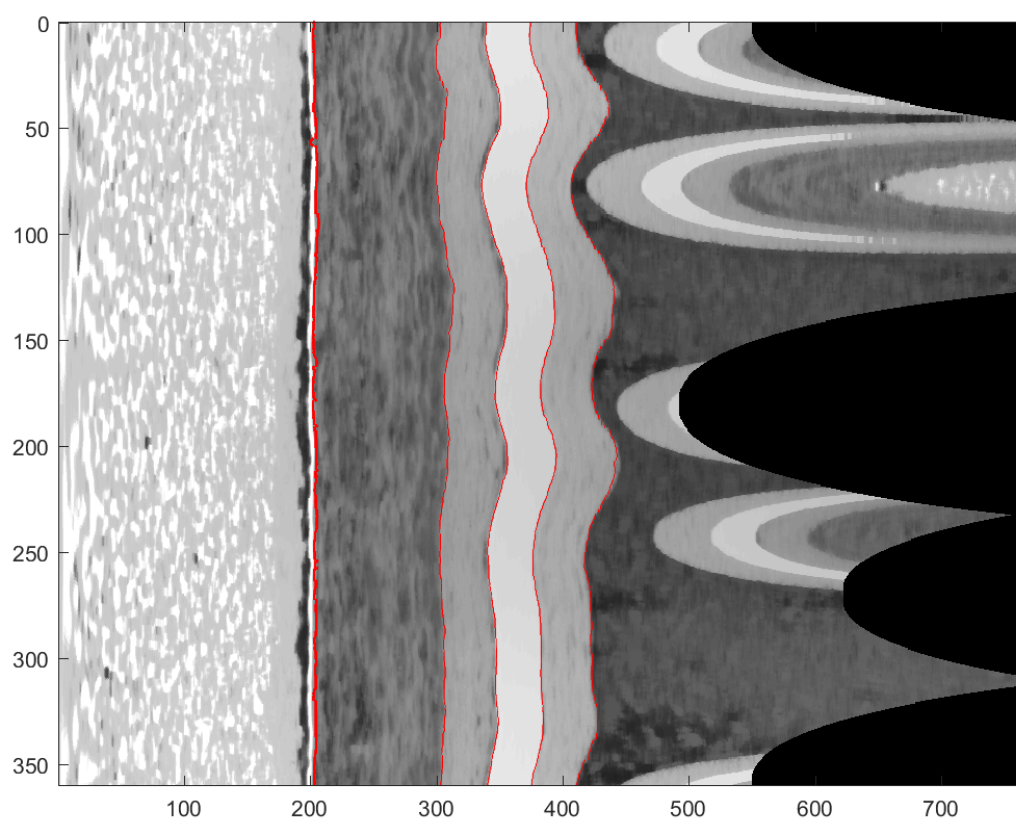
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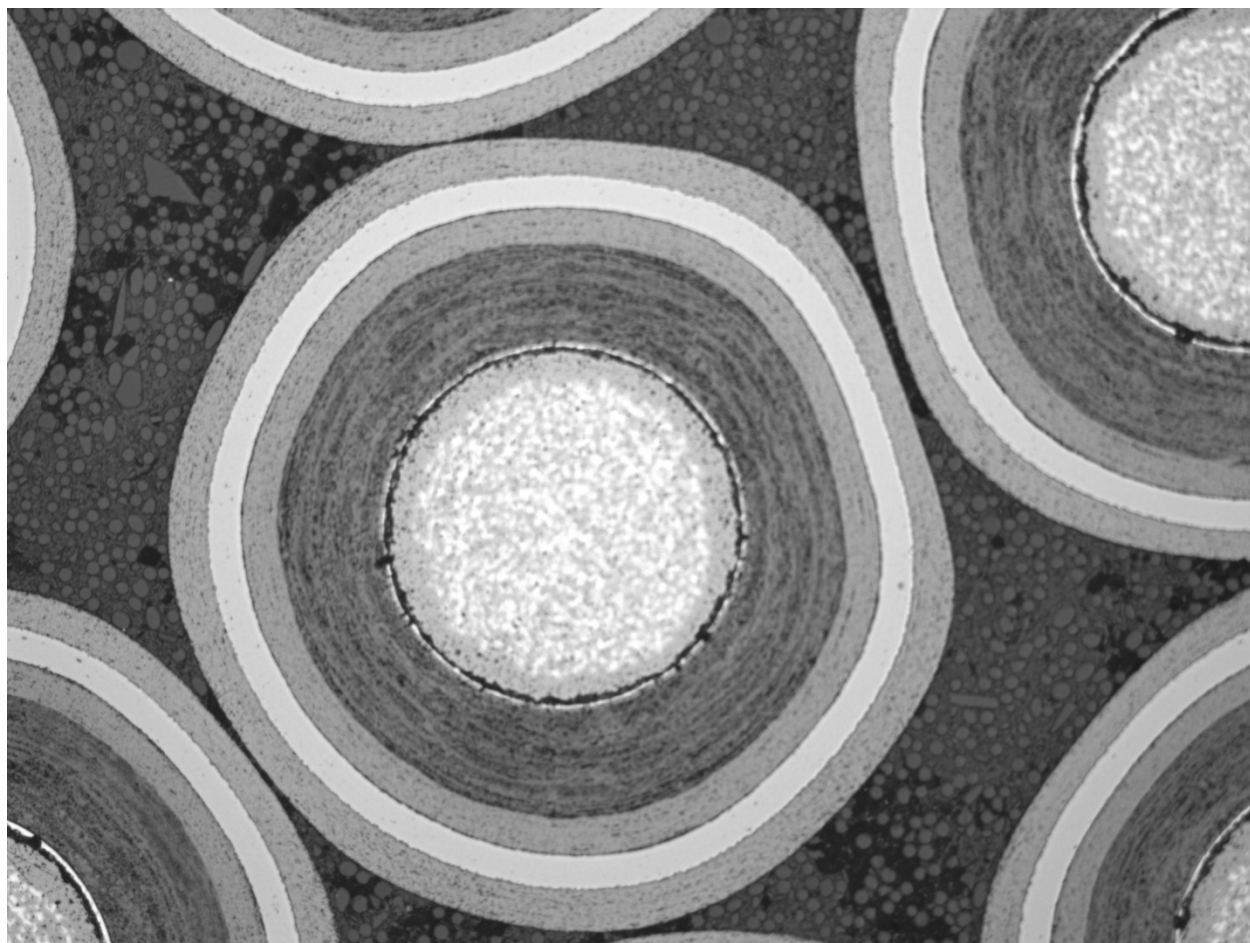
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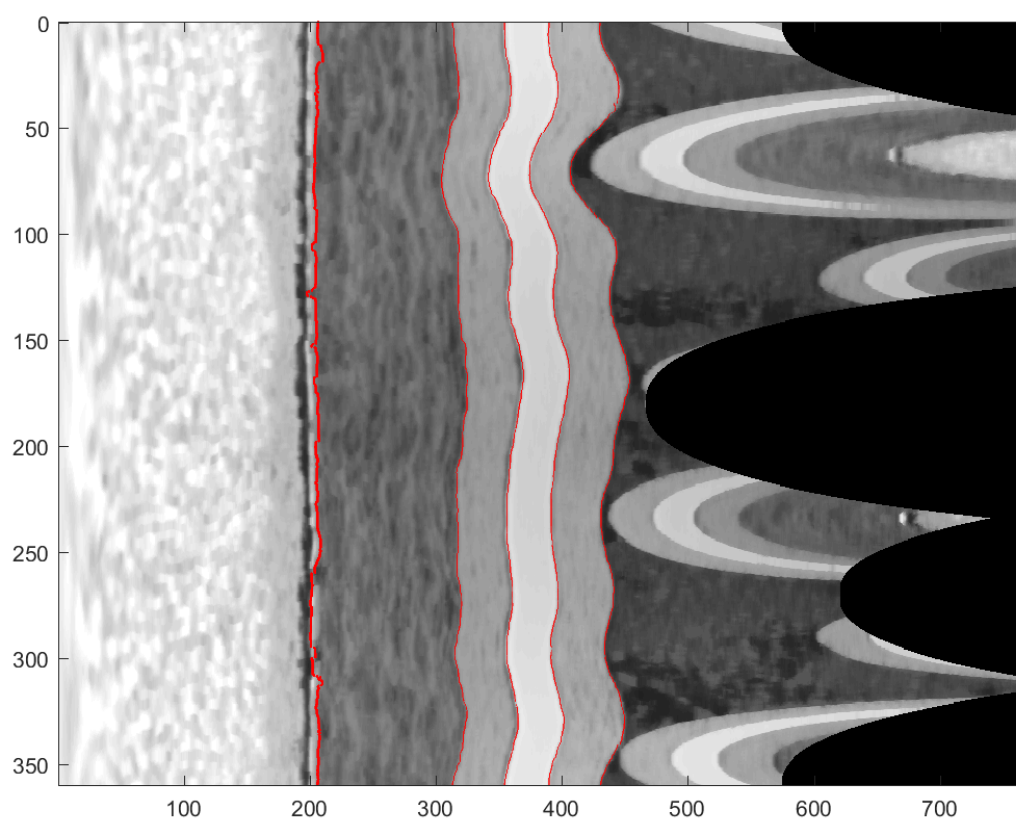
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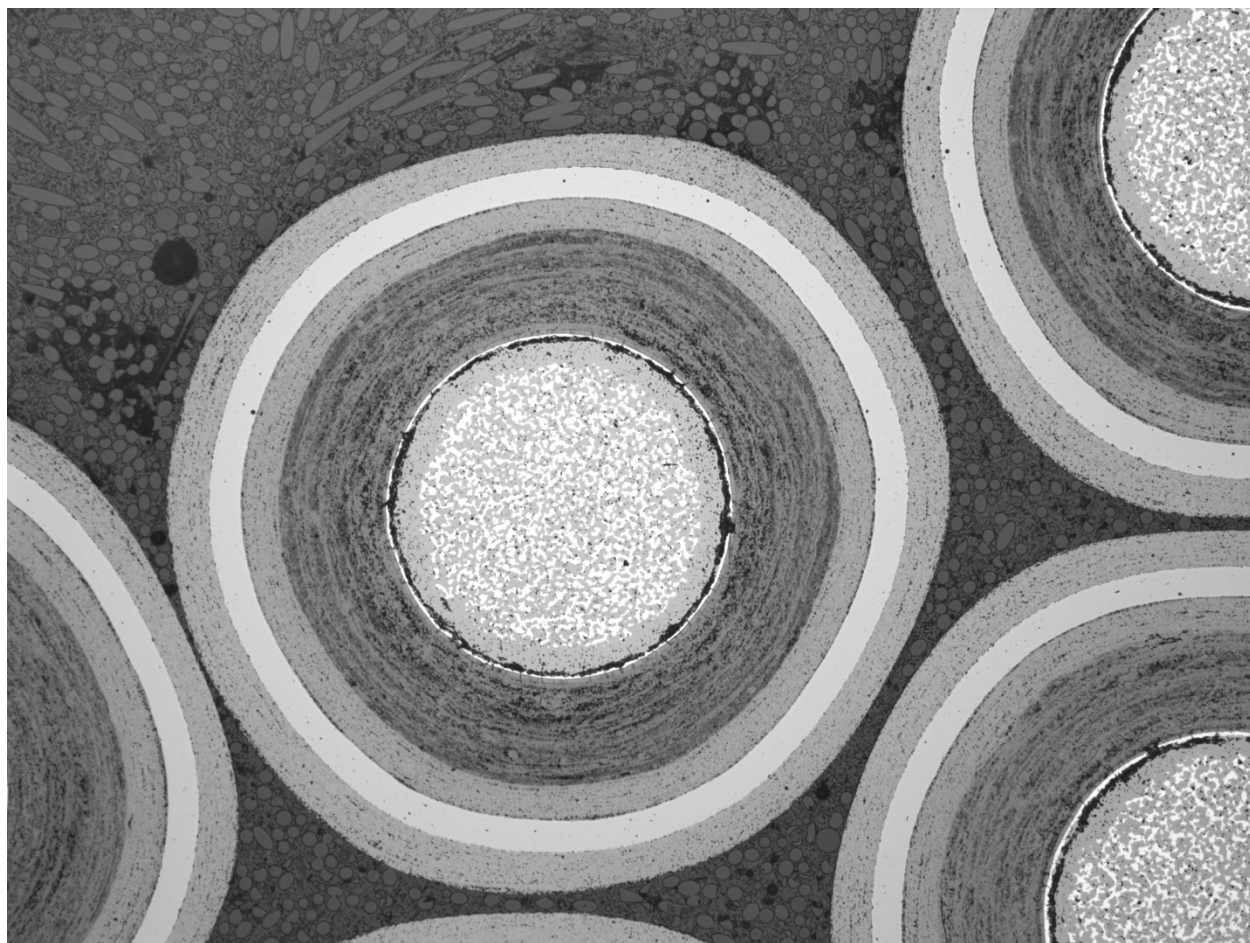


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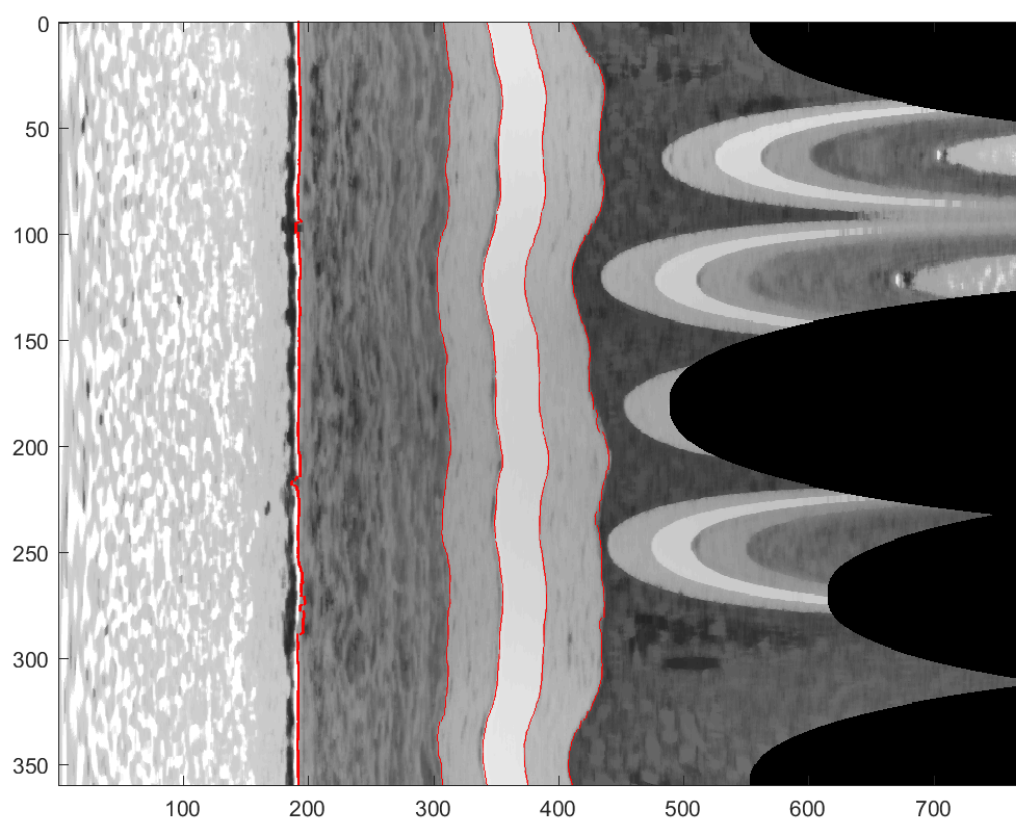


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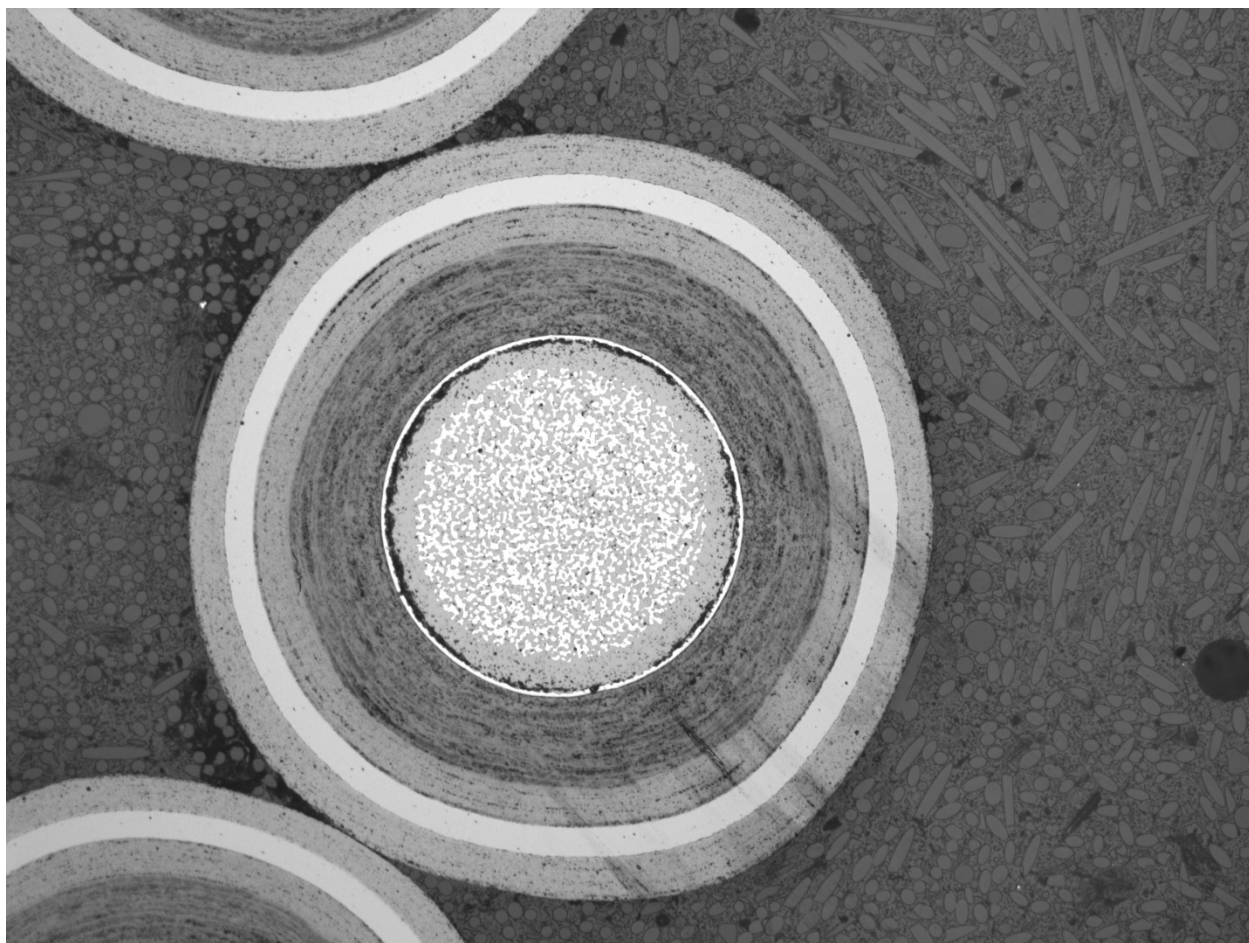




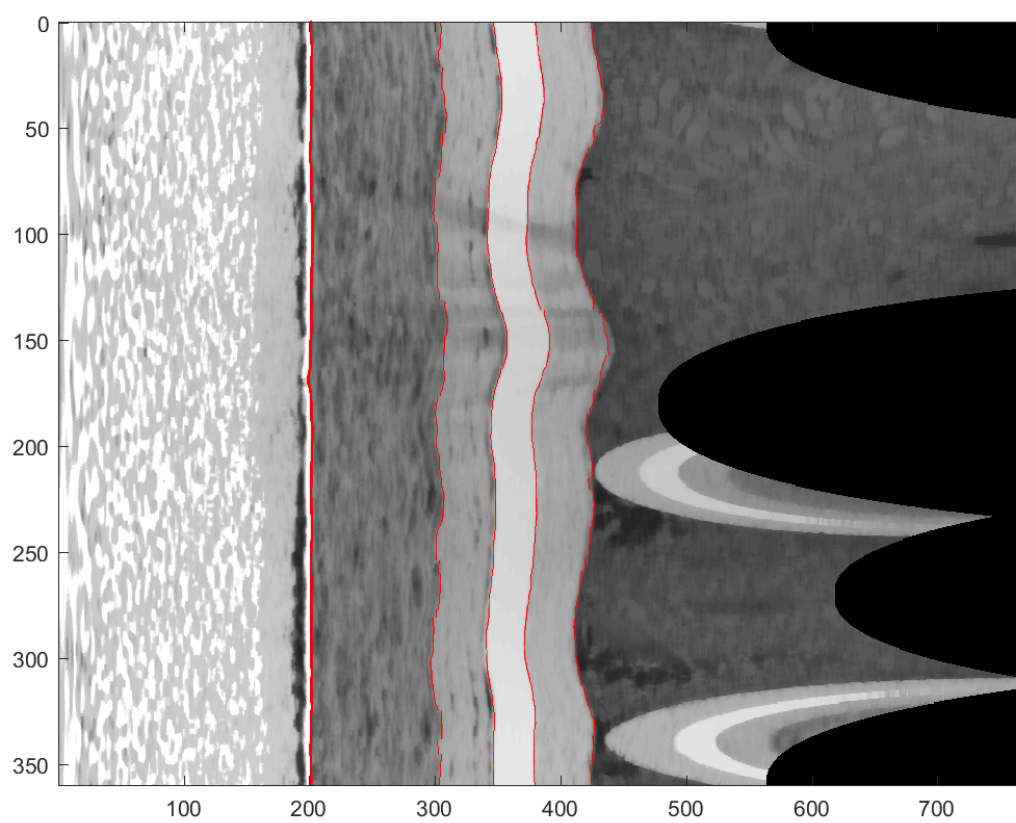
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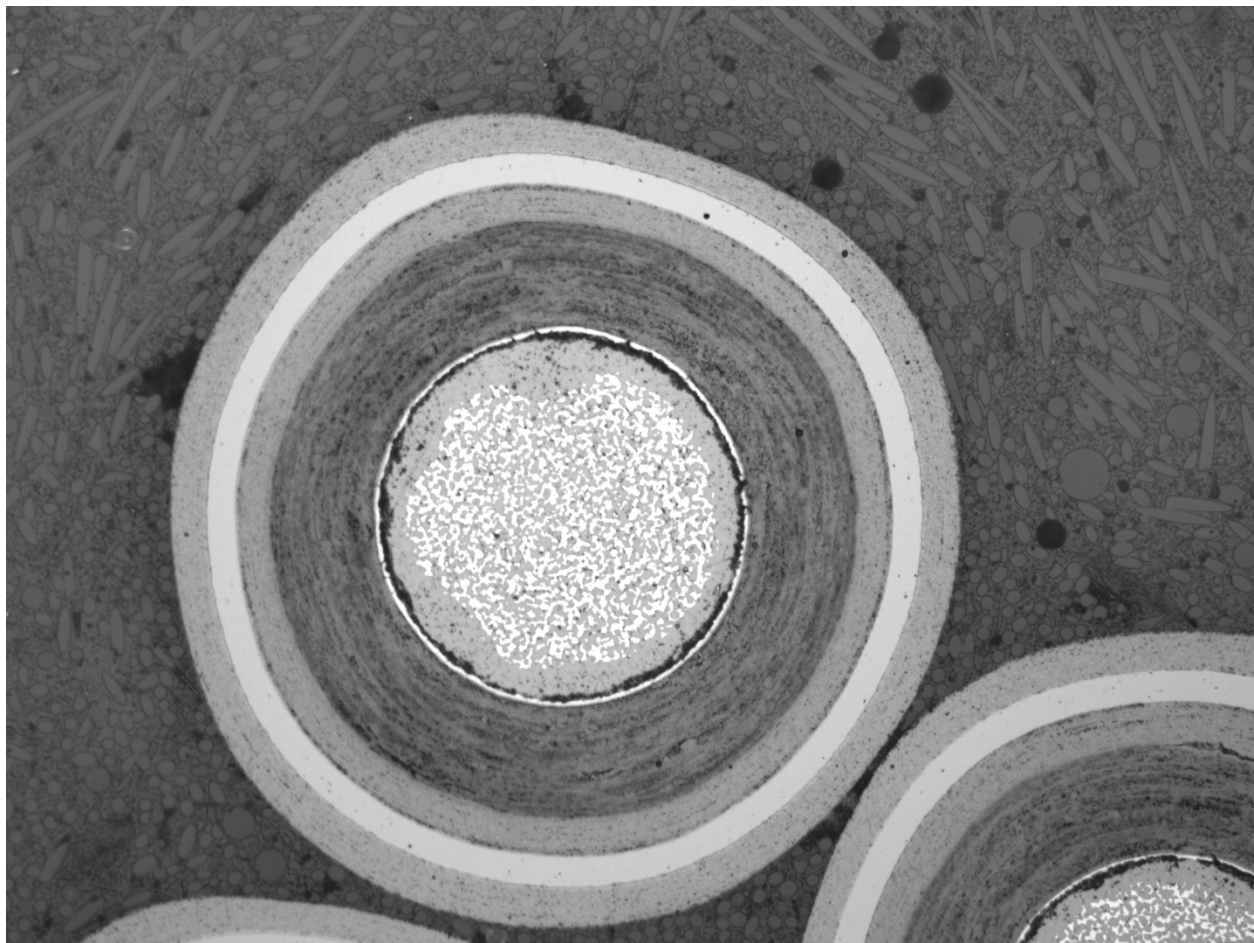
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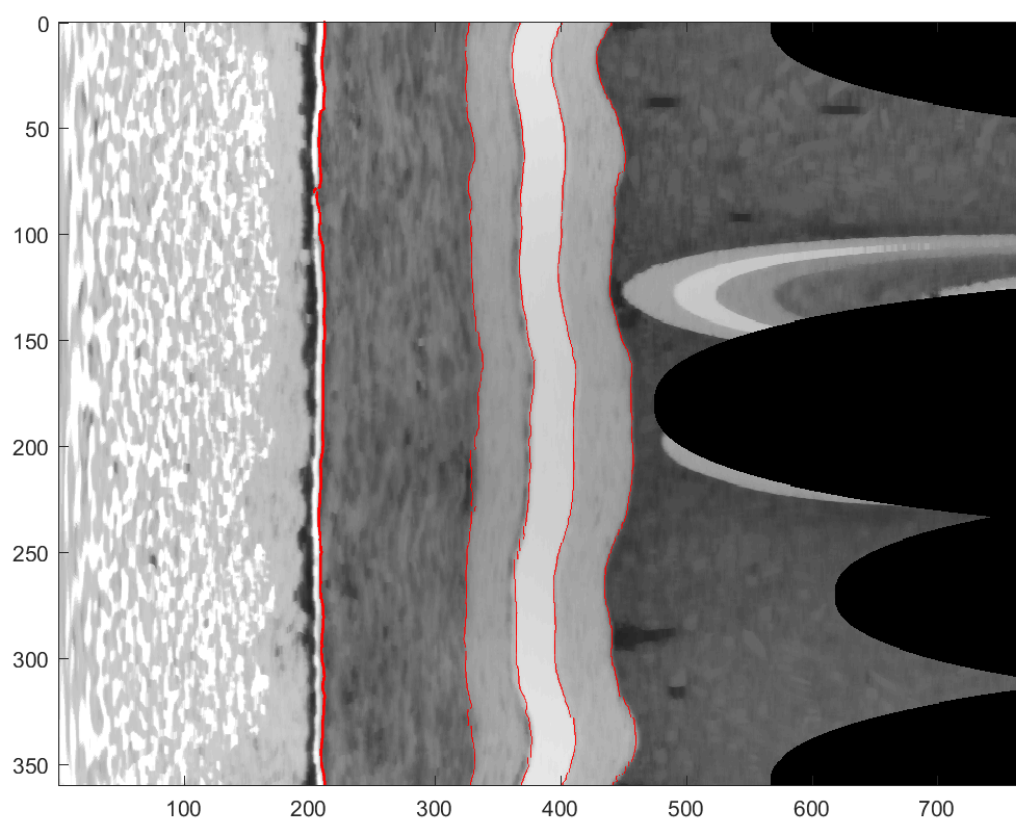
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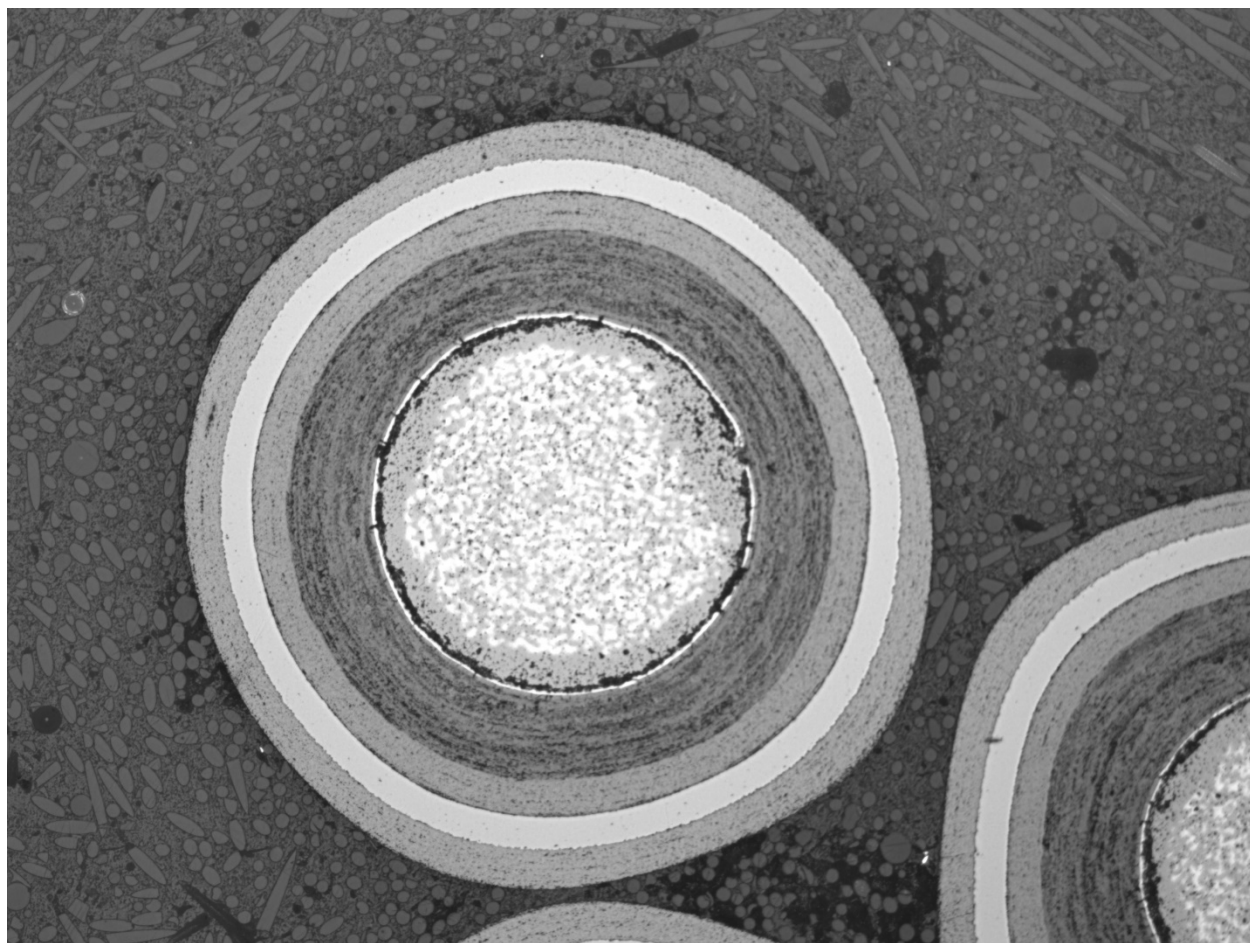


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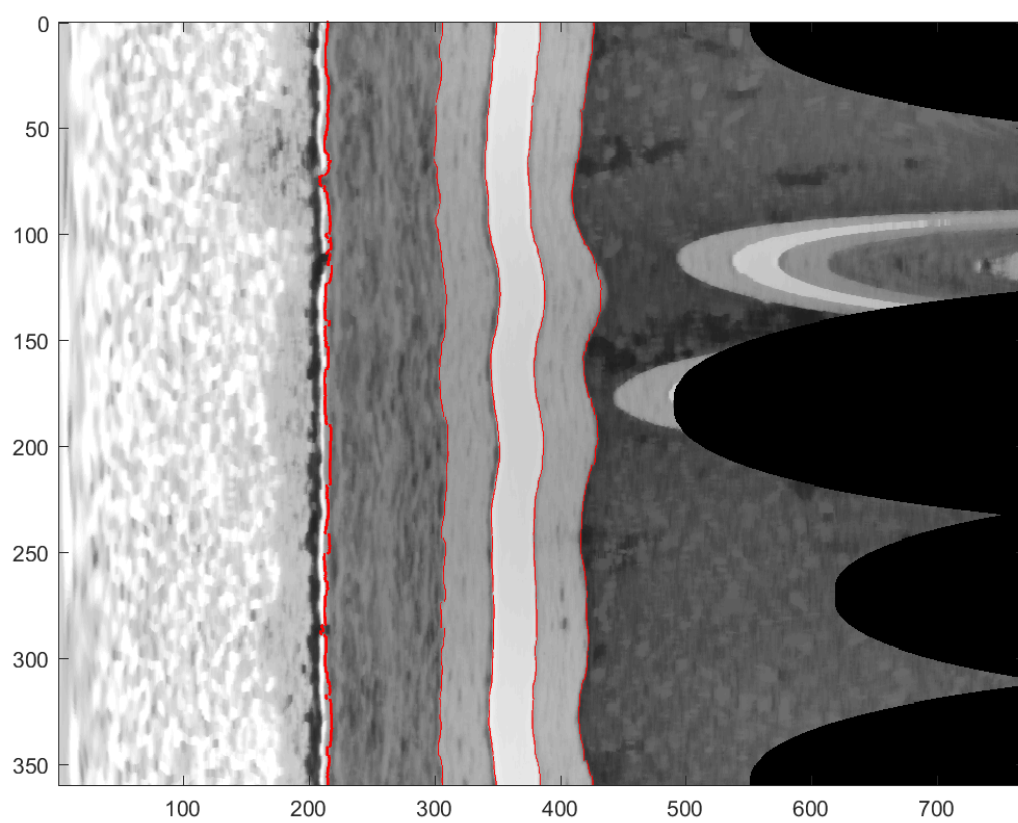
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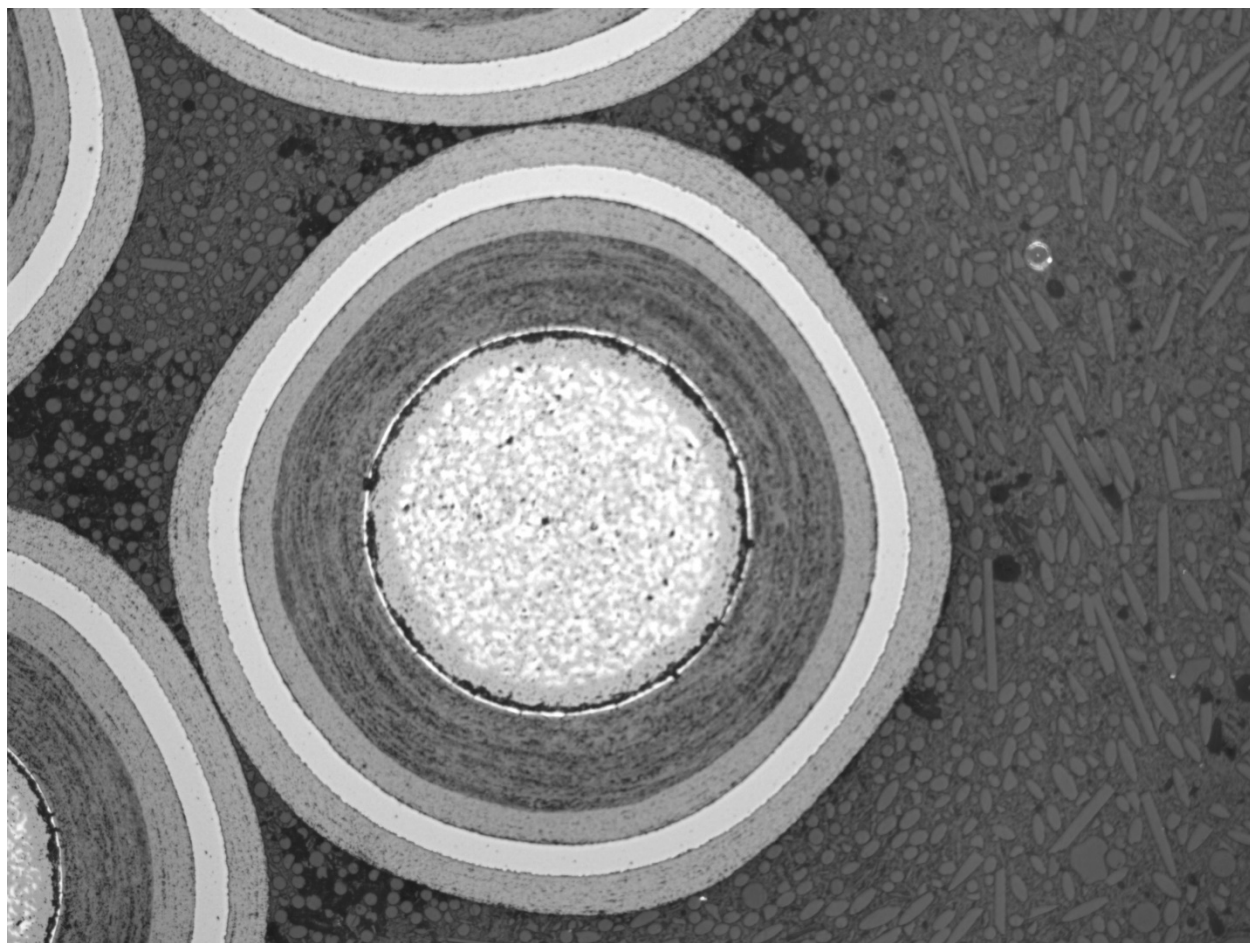


P16070801N063

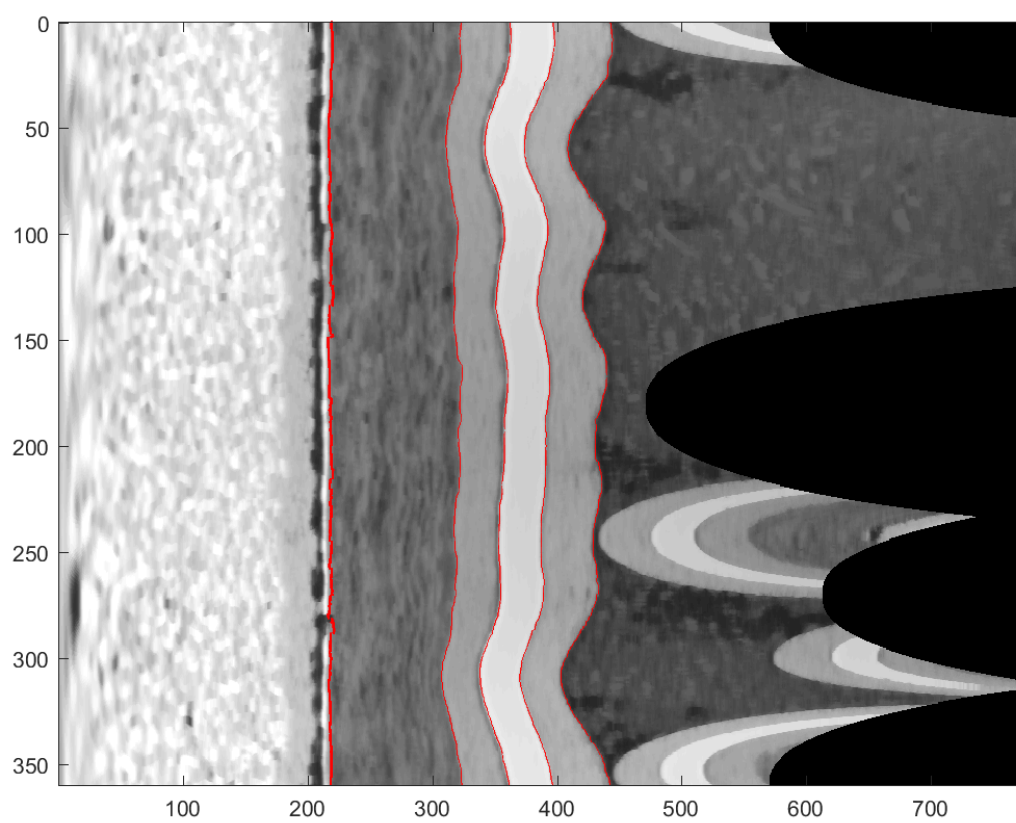




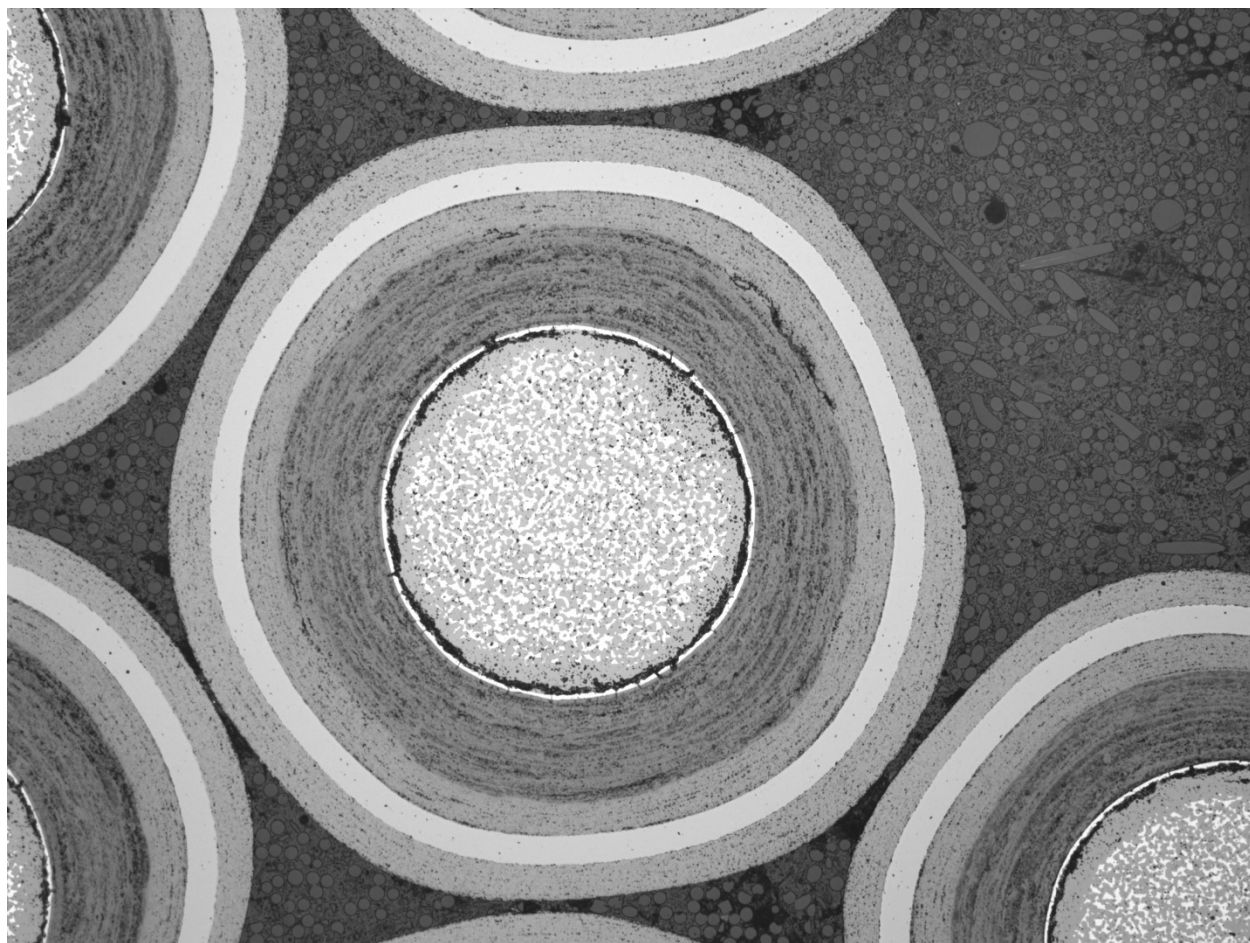
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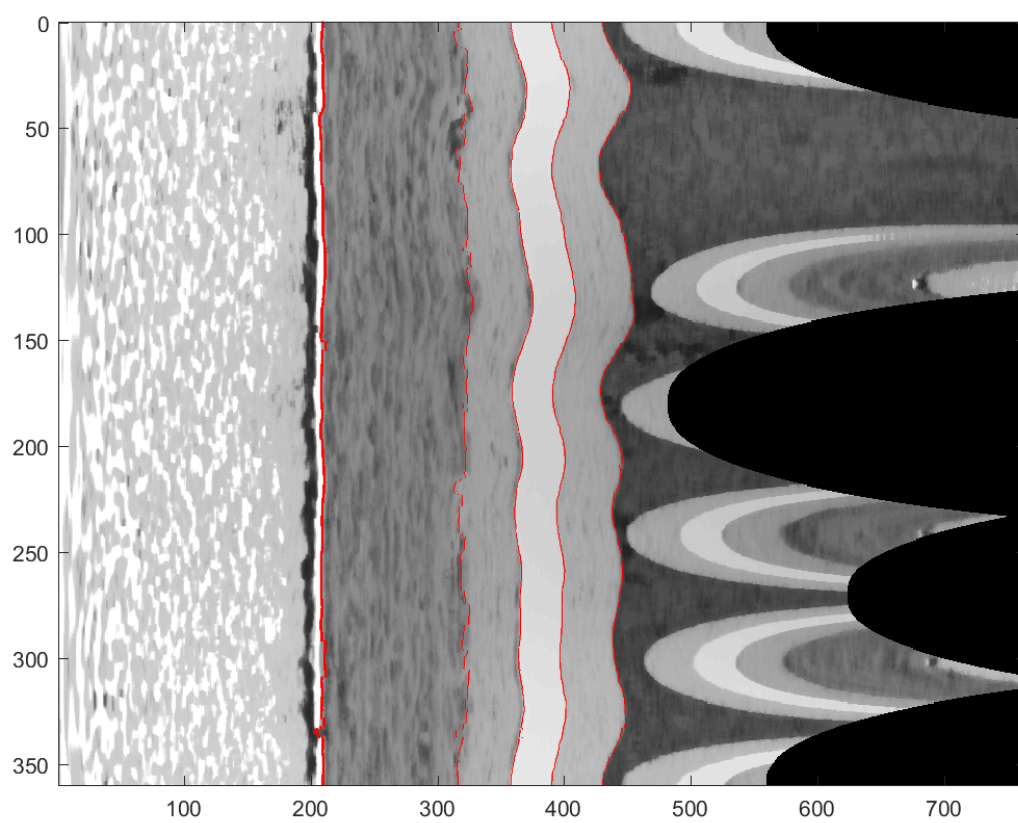
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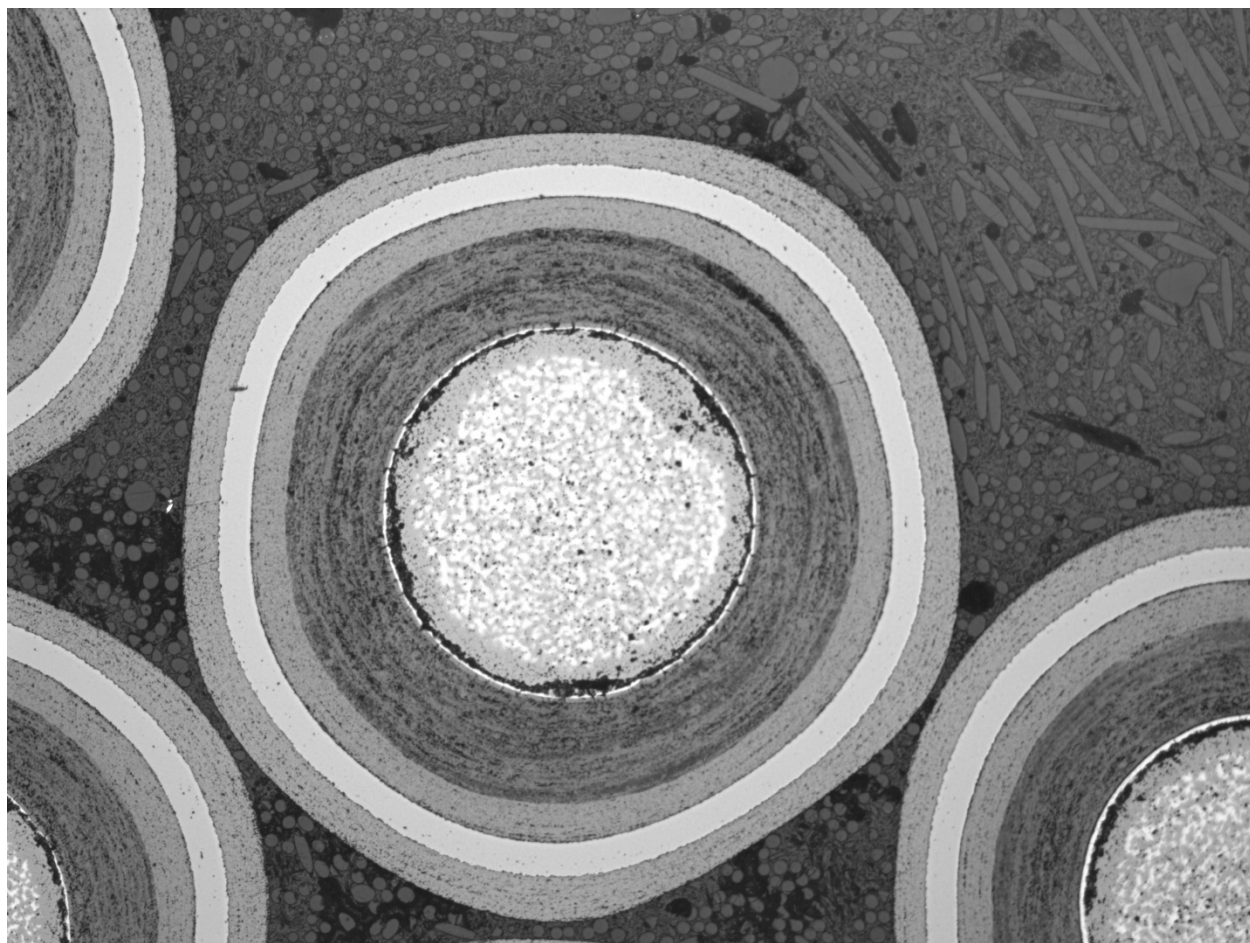
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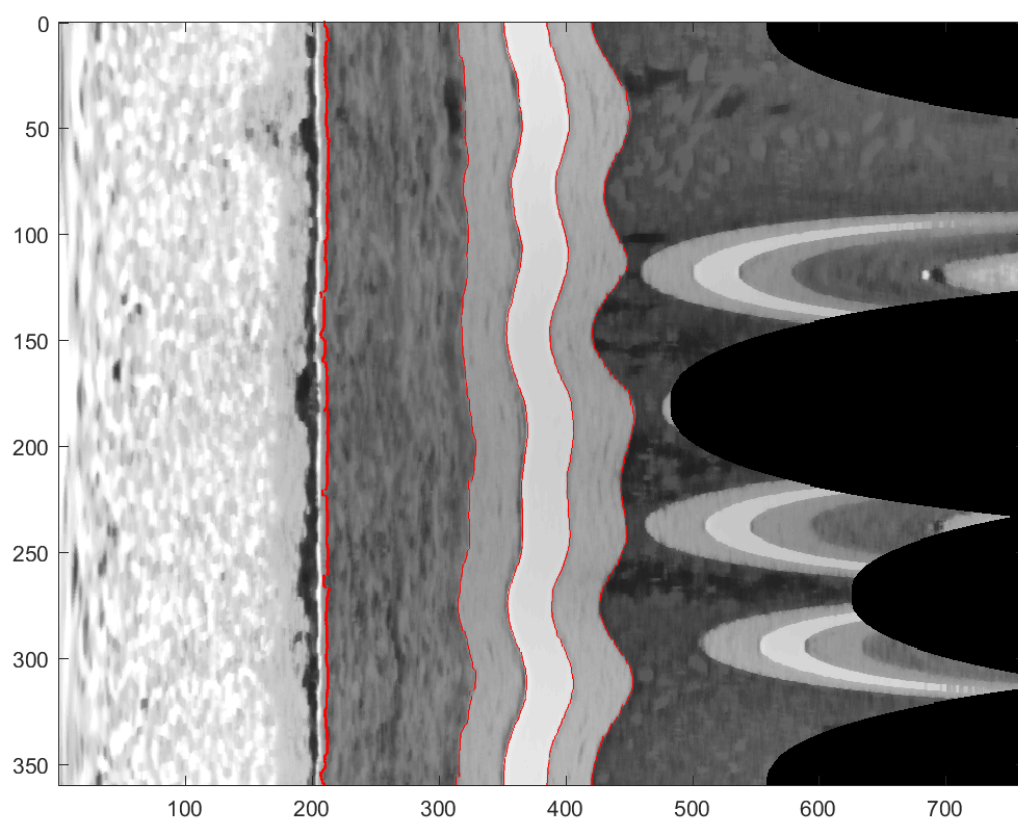
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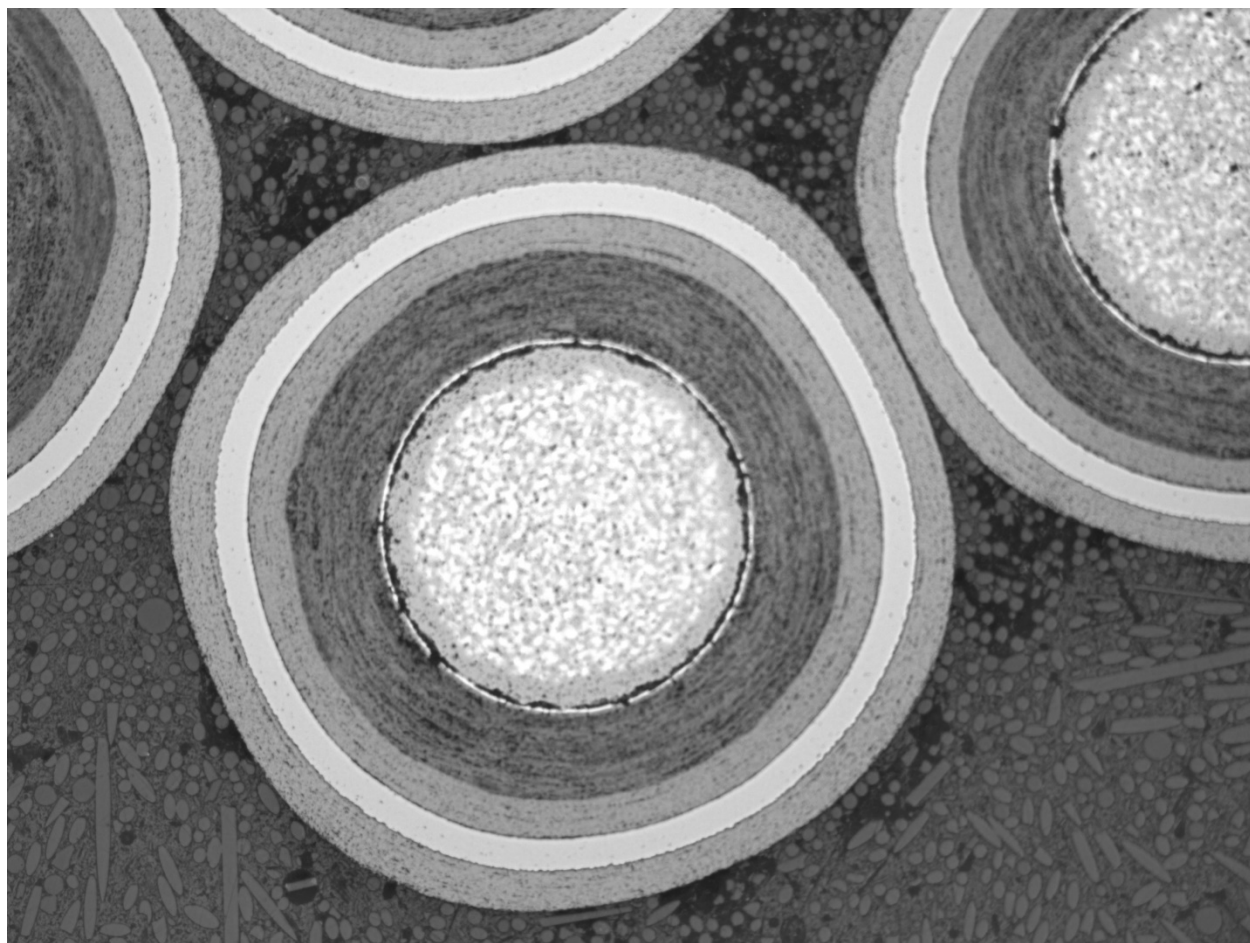


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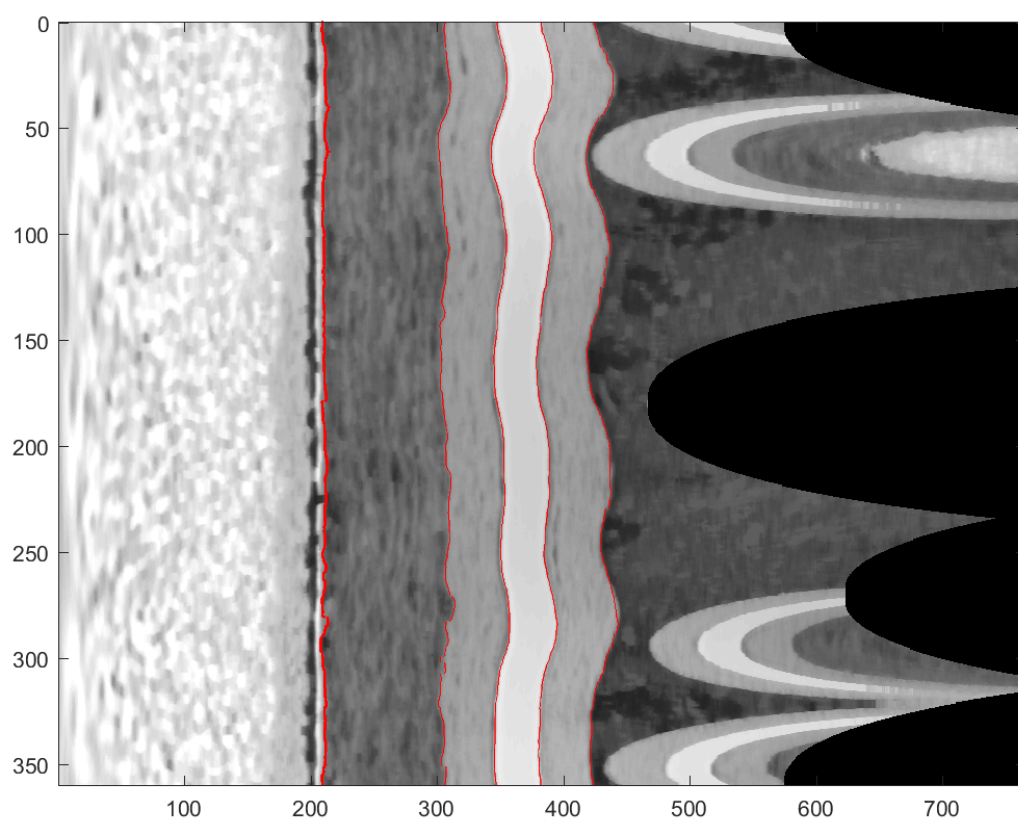


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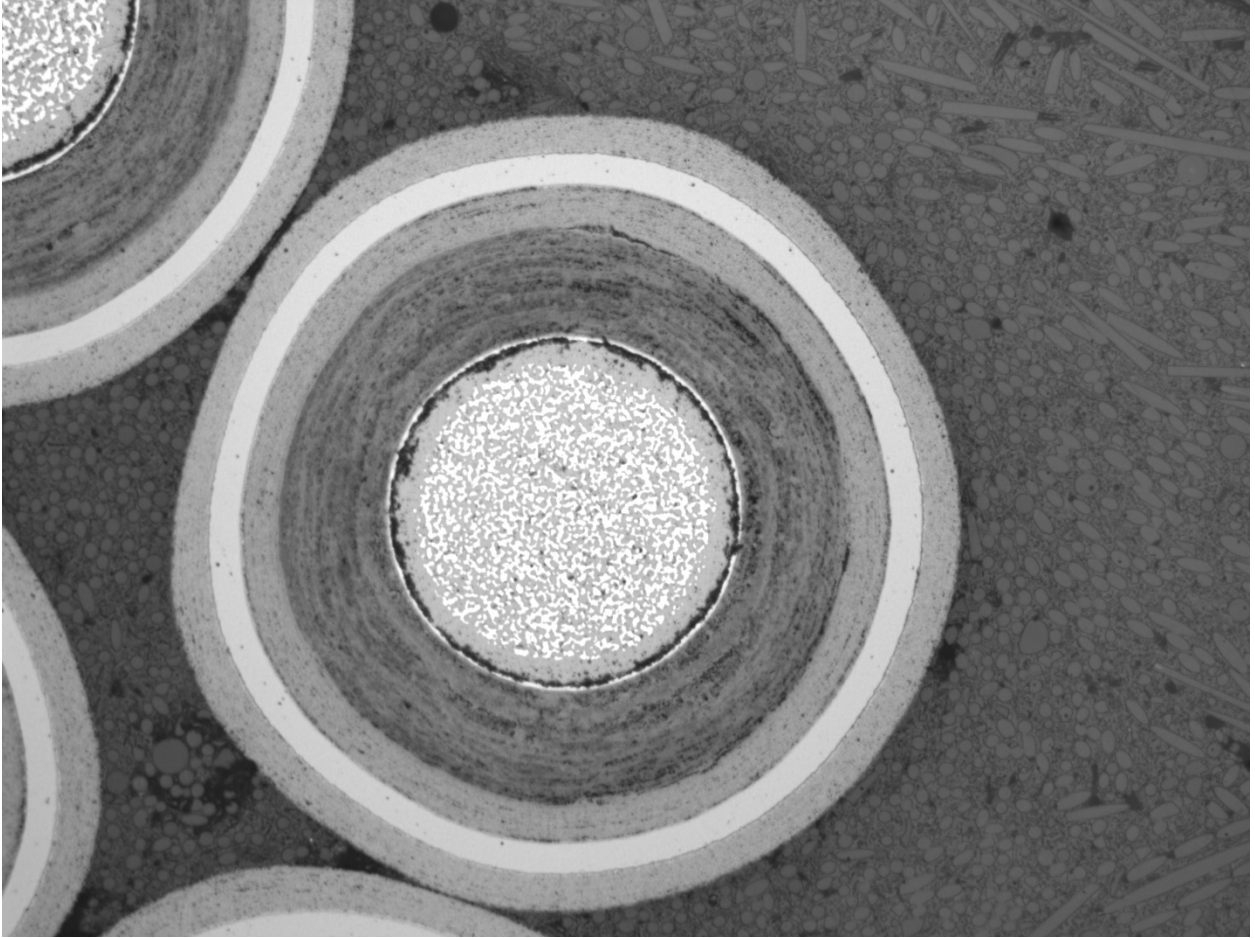




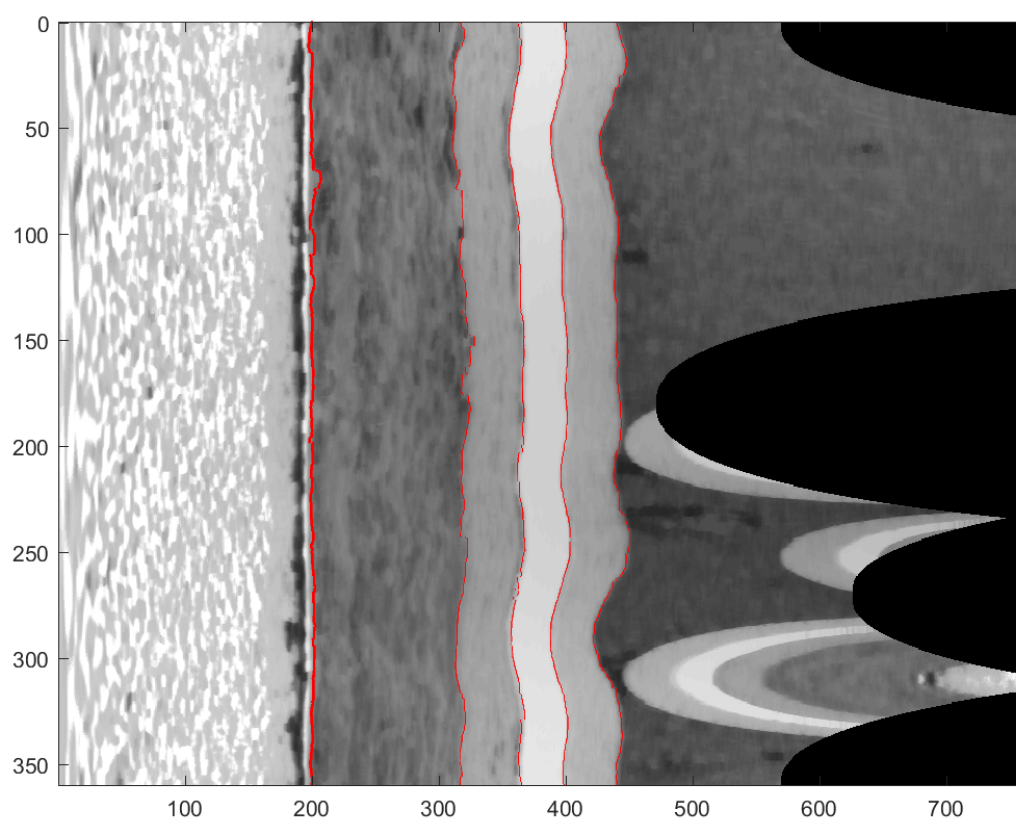
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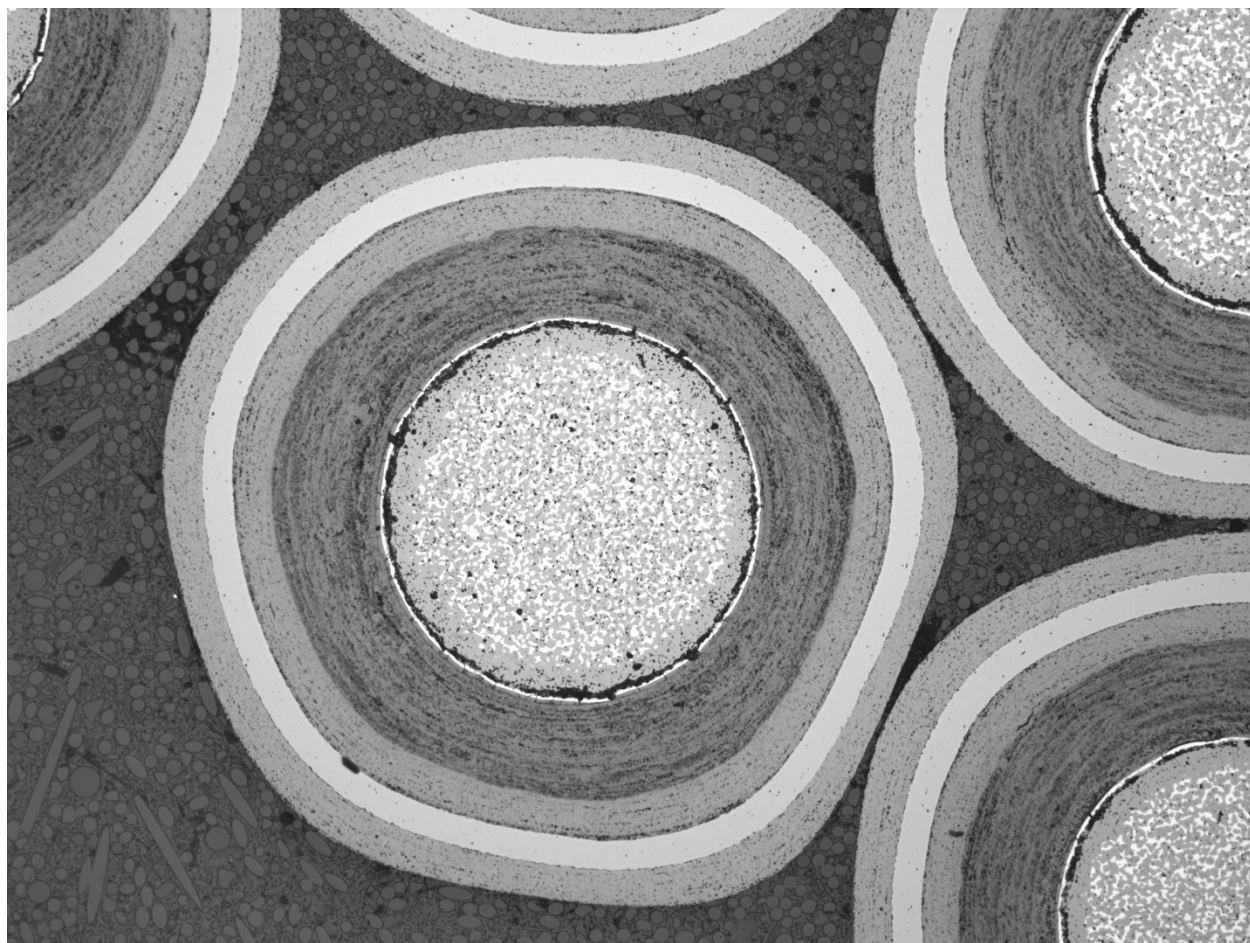
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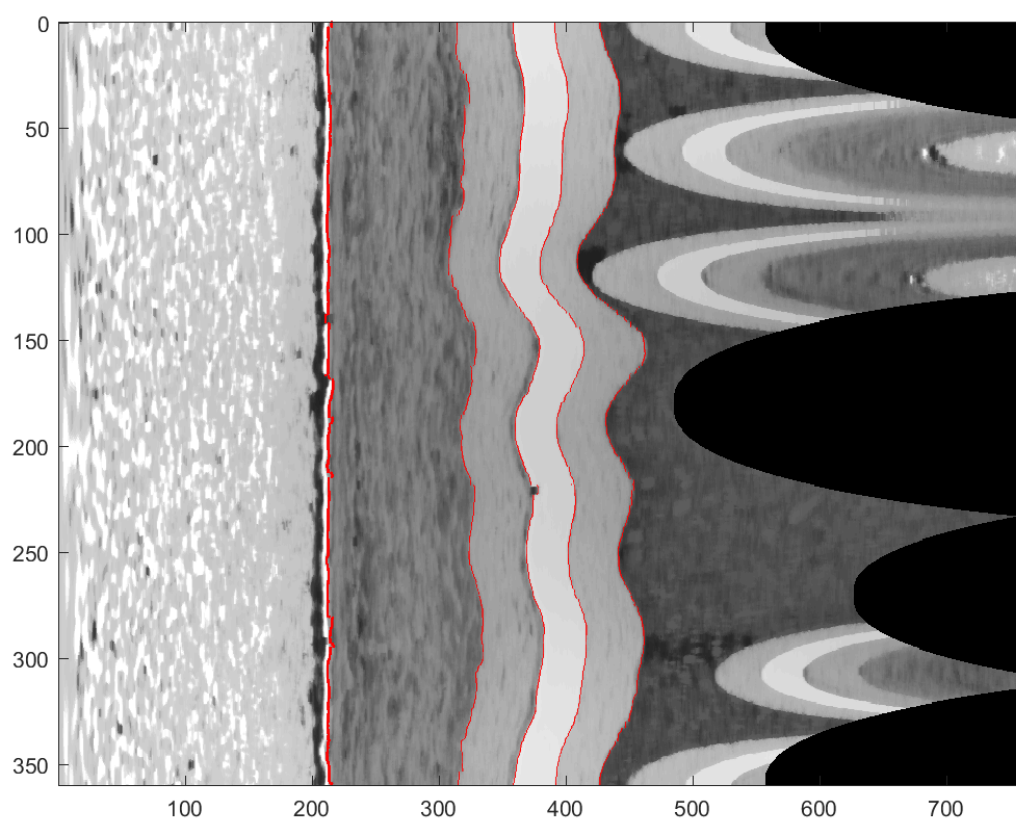
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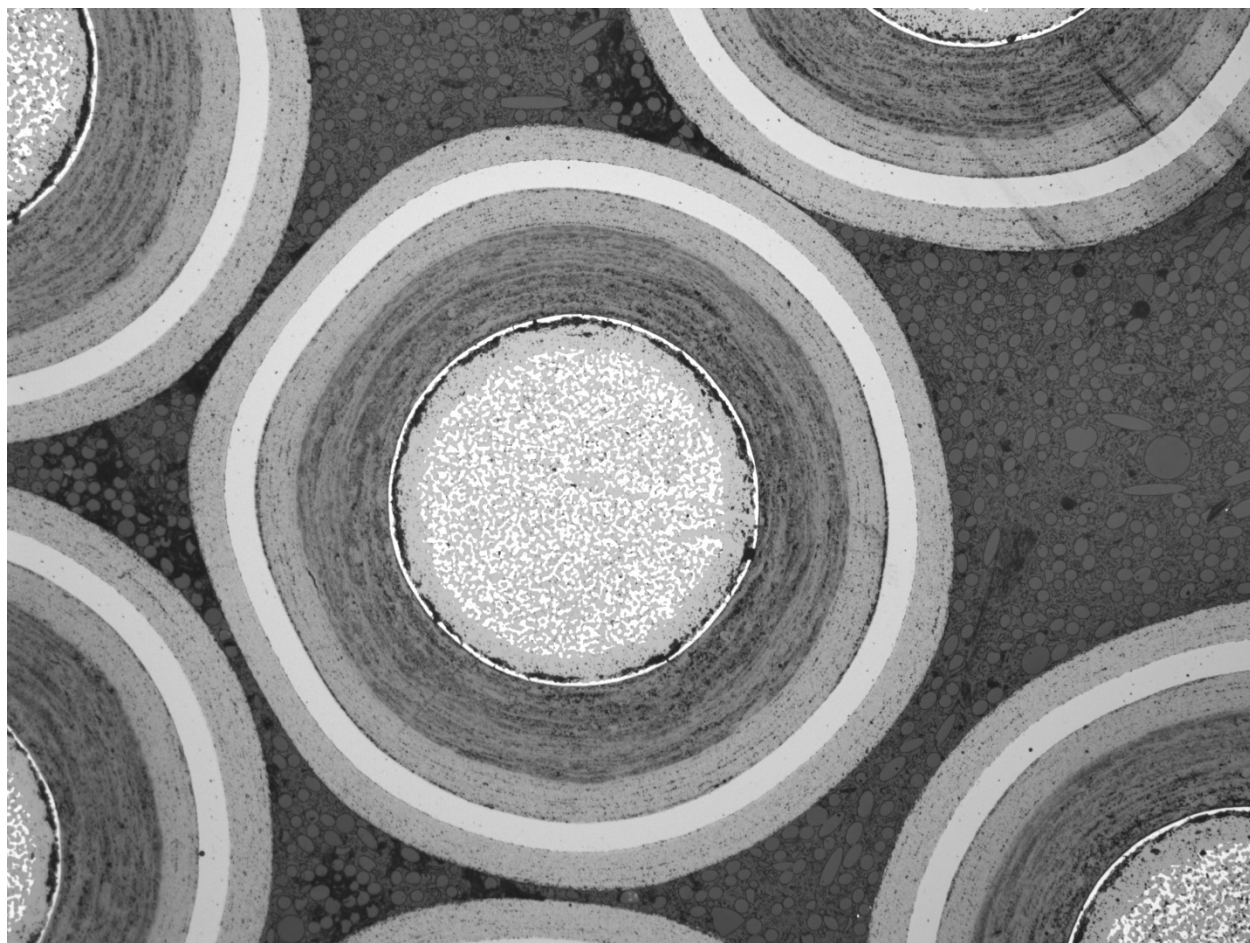
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P16070801N070

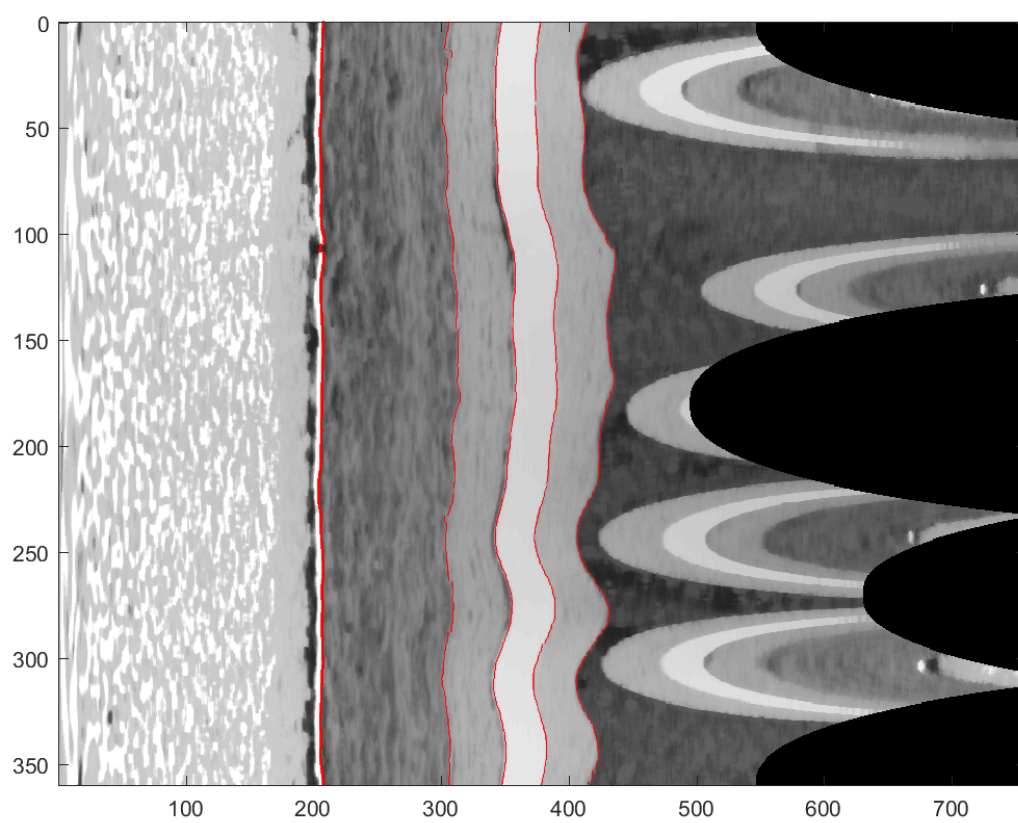


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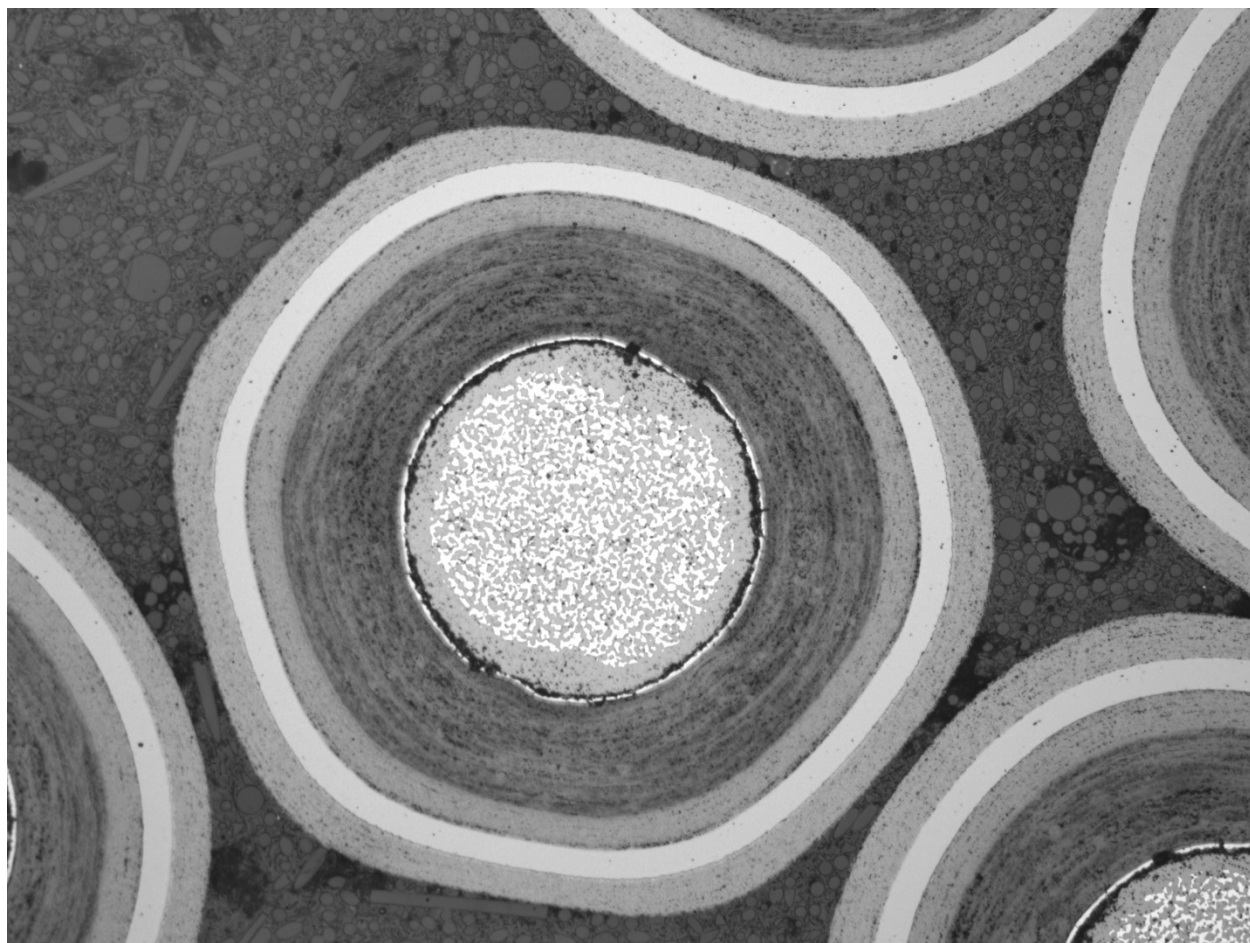


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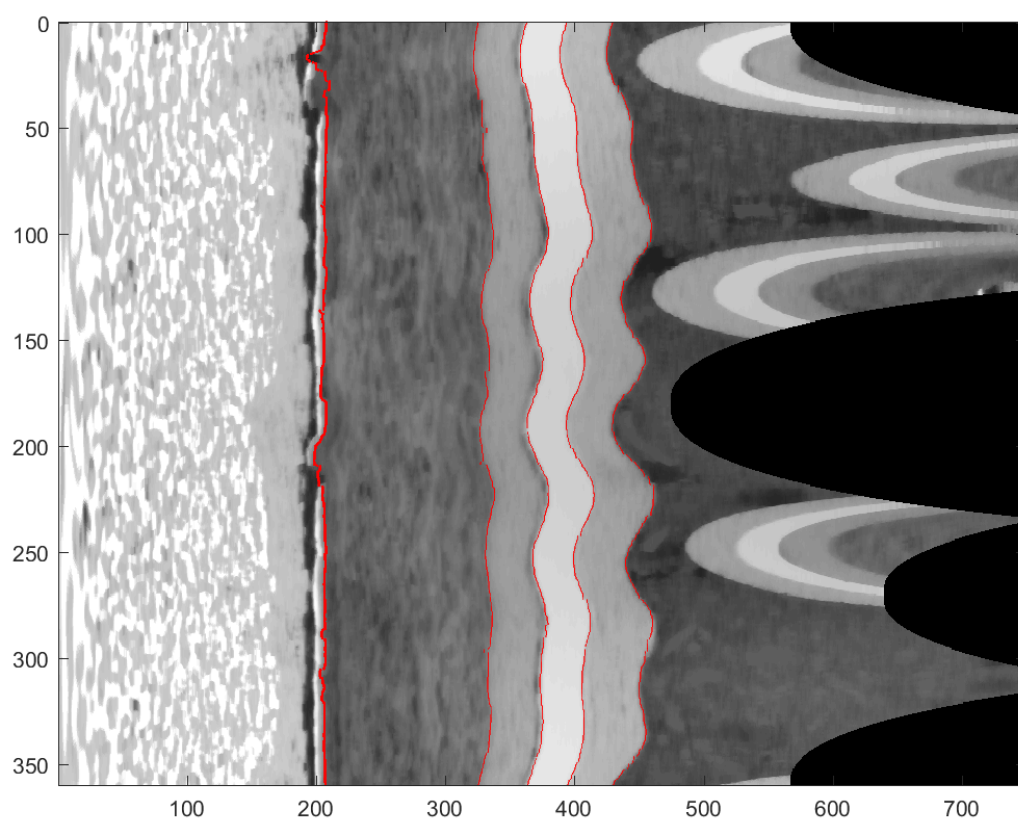




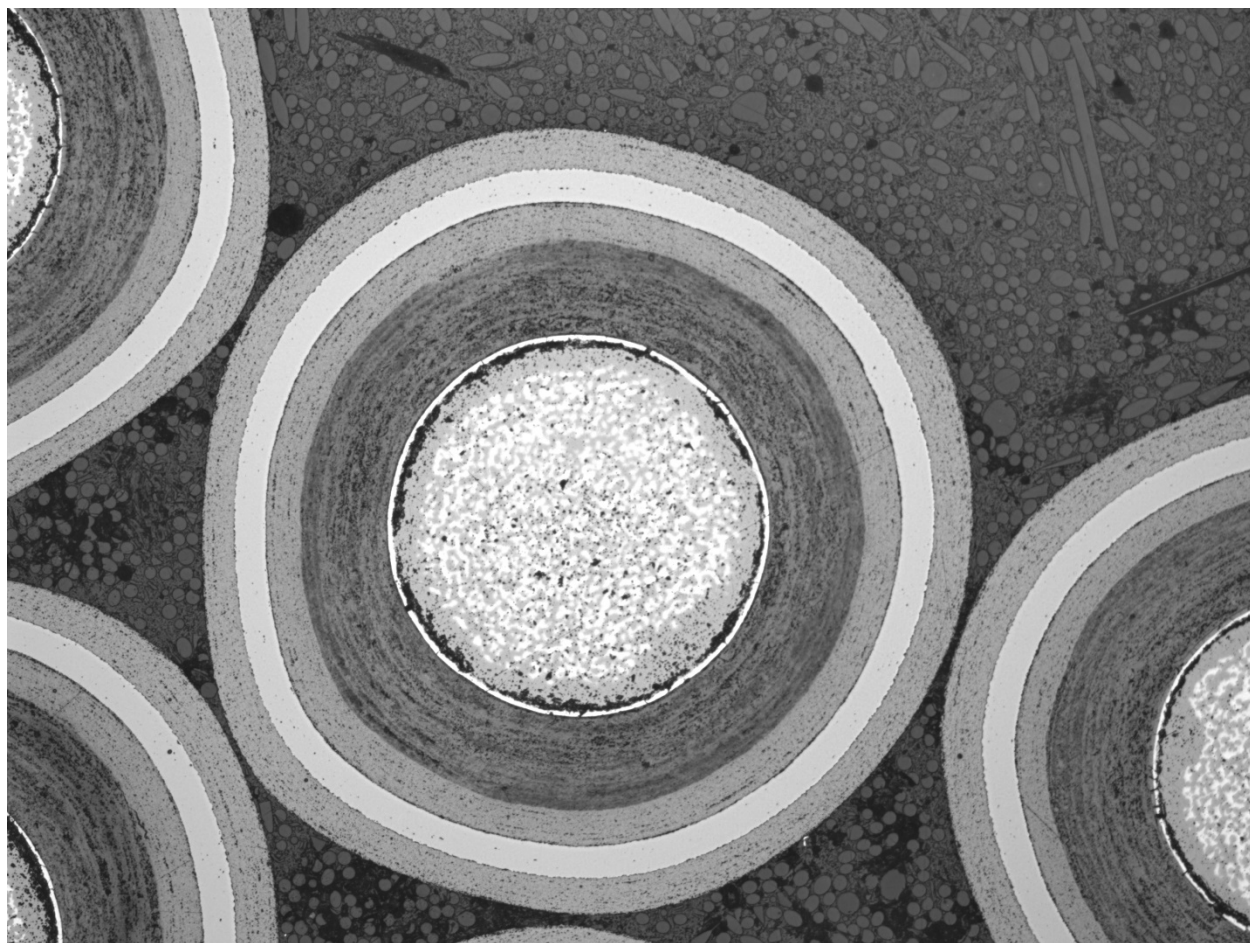
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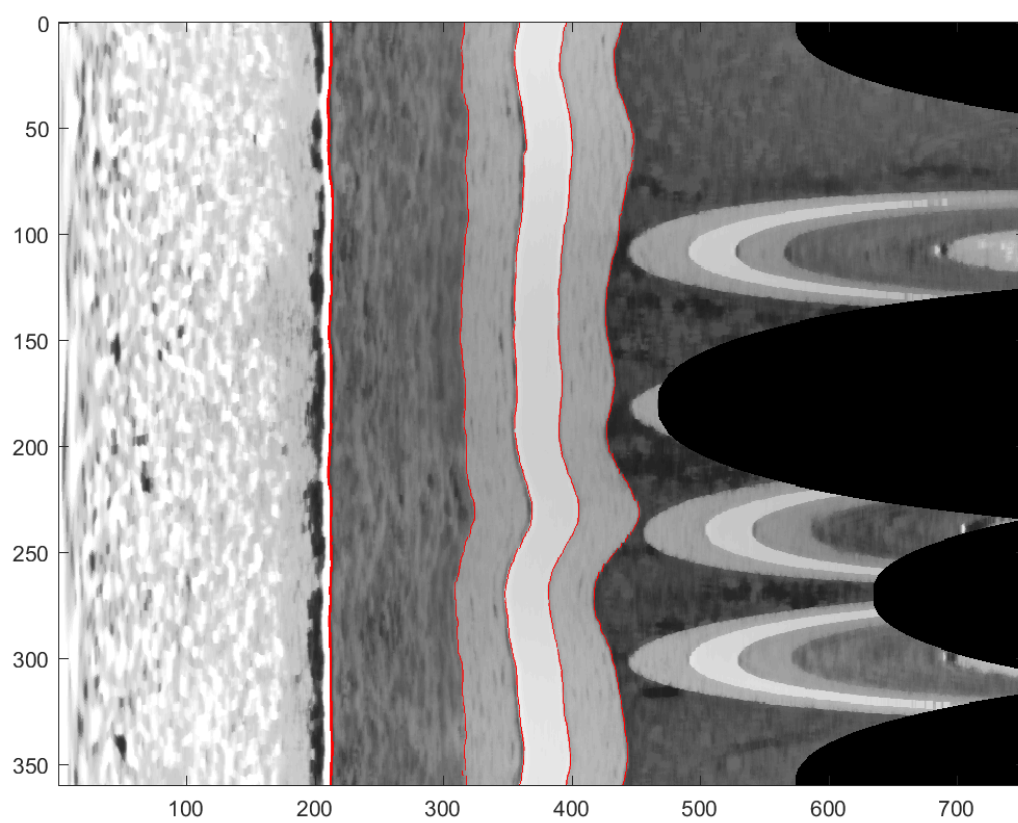
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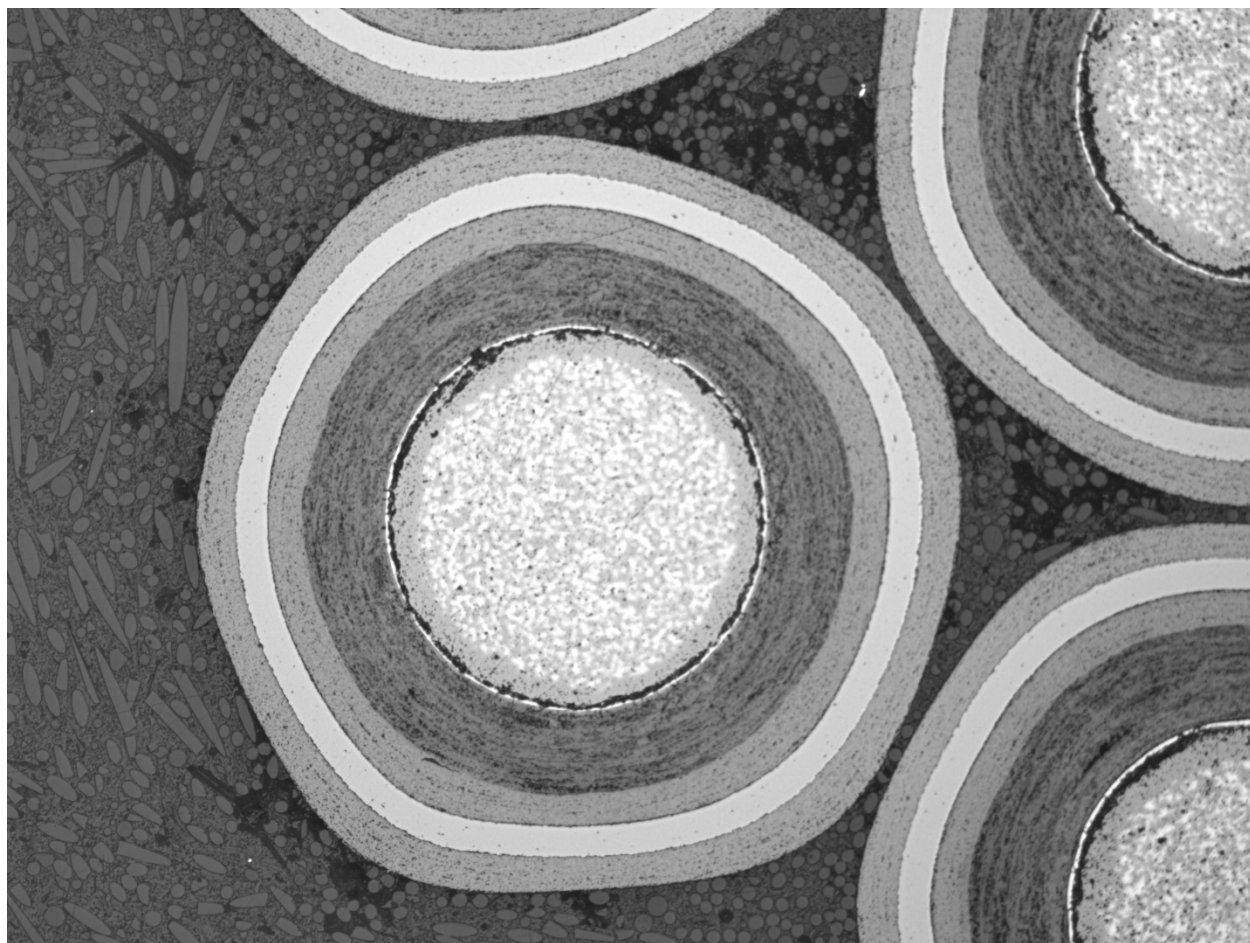
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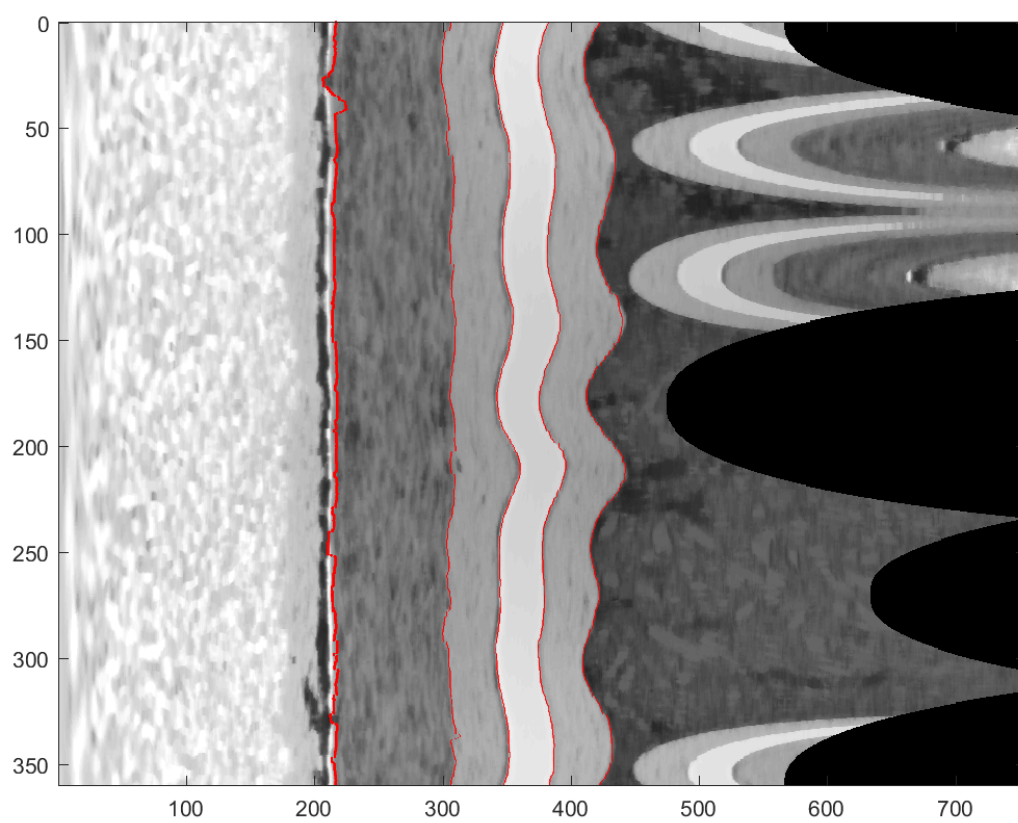
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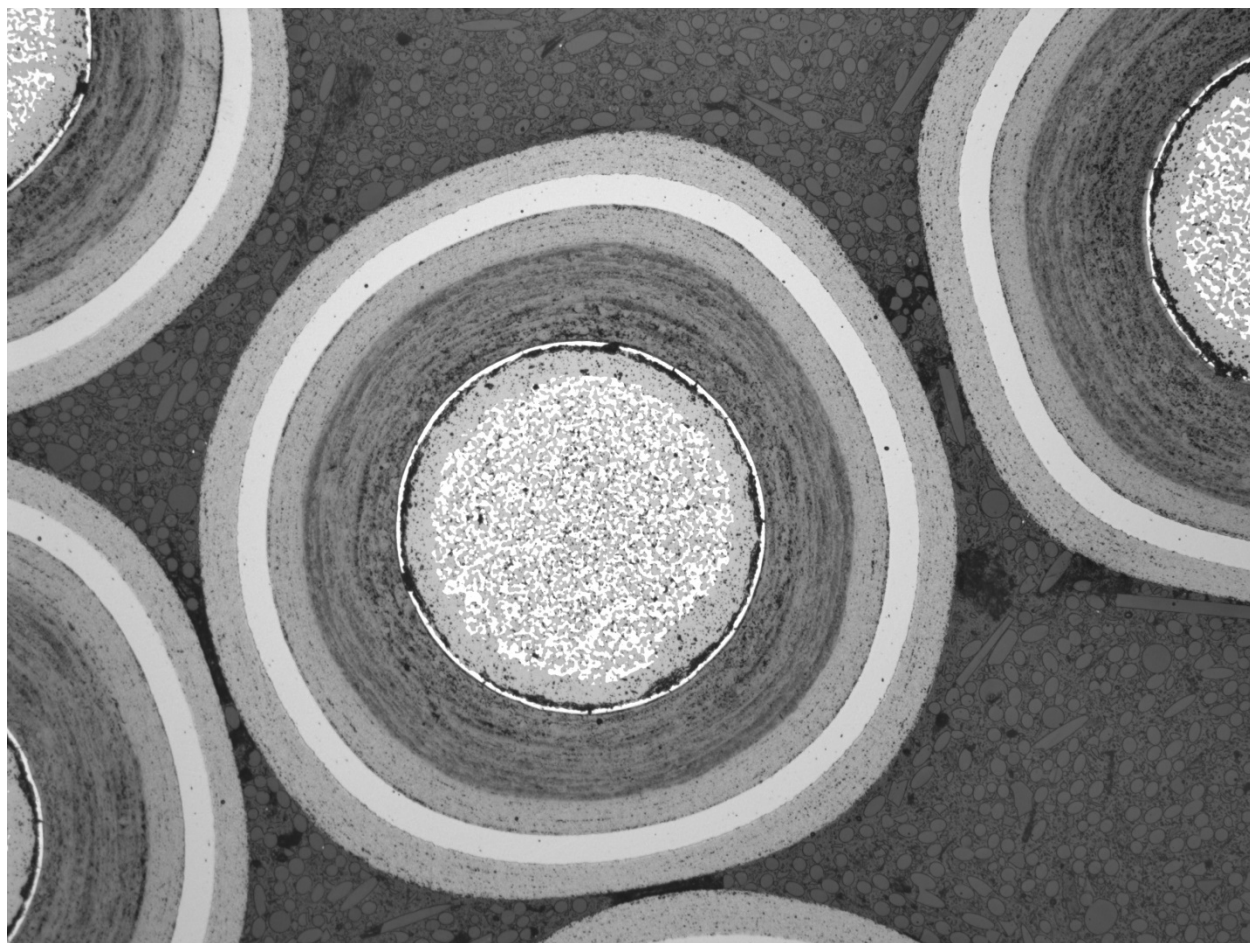


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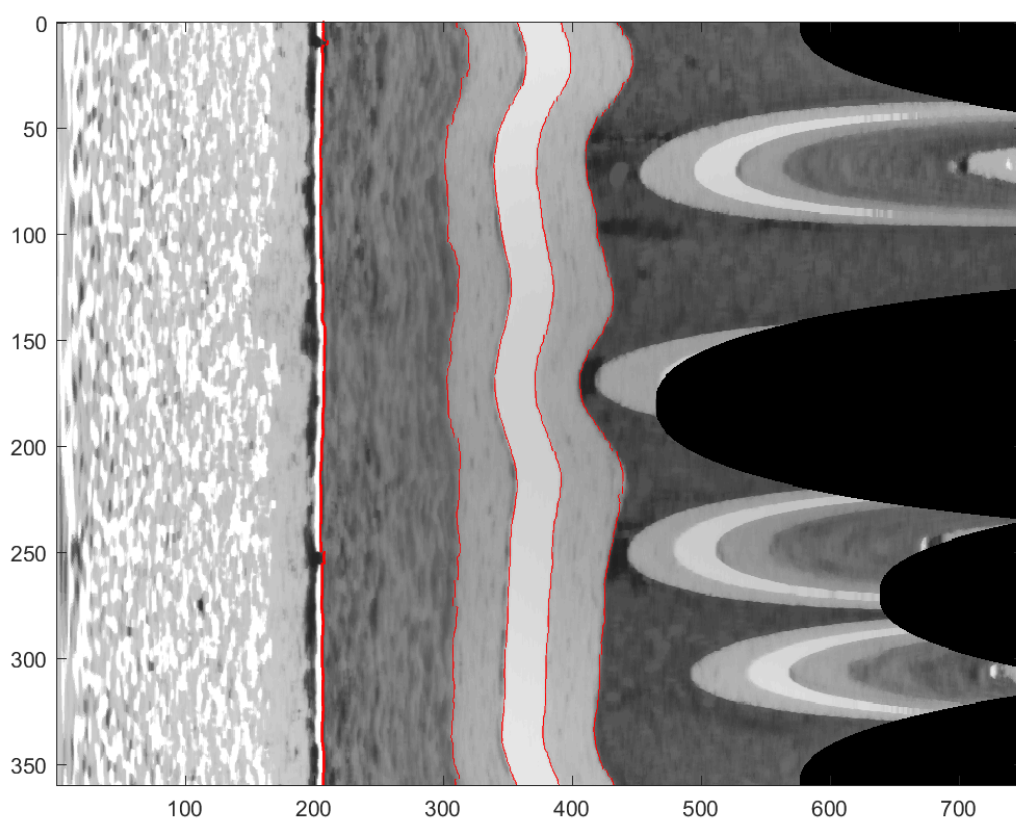


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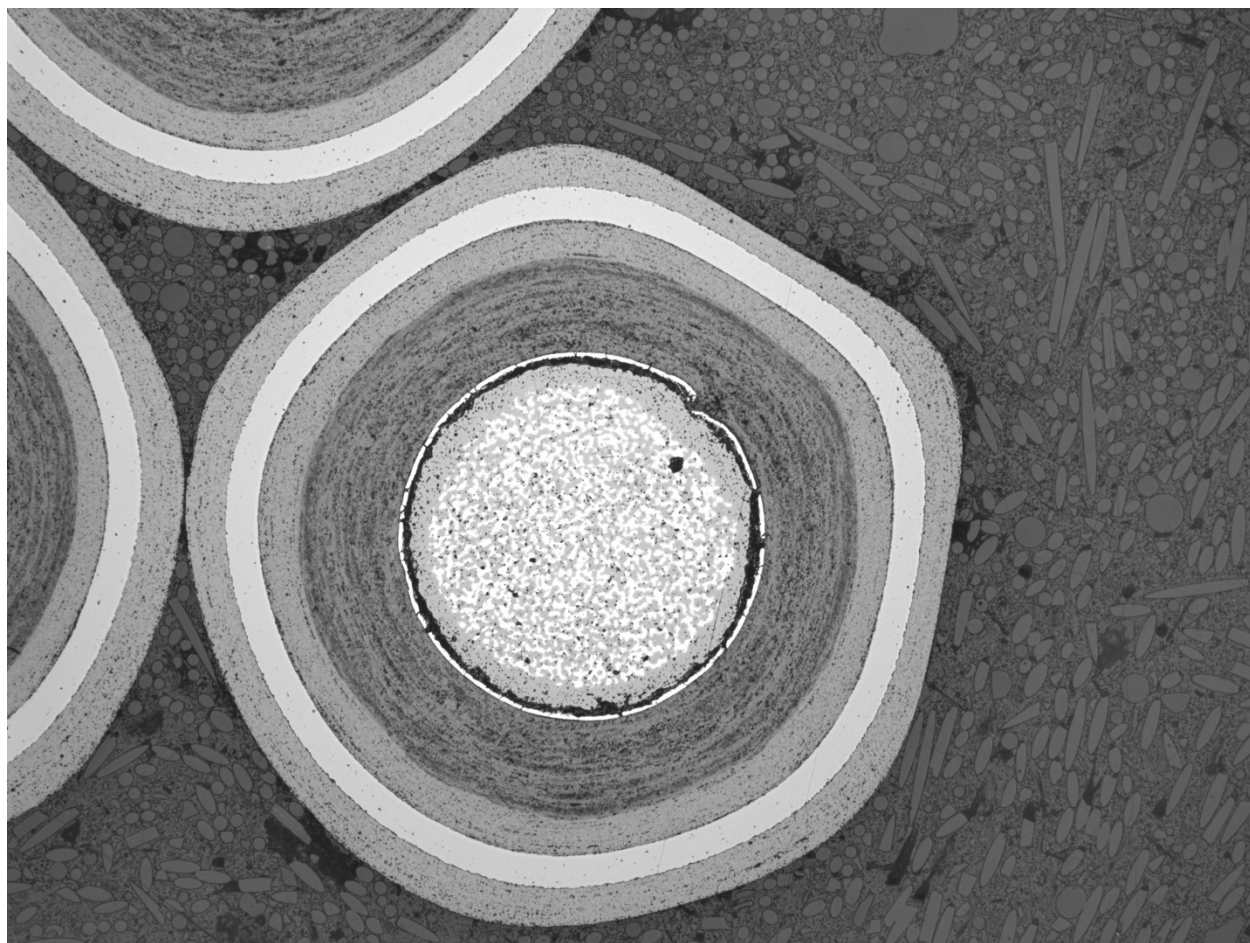




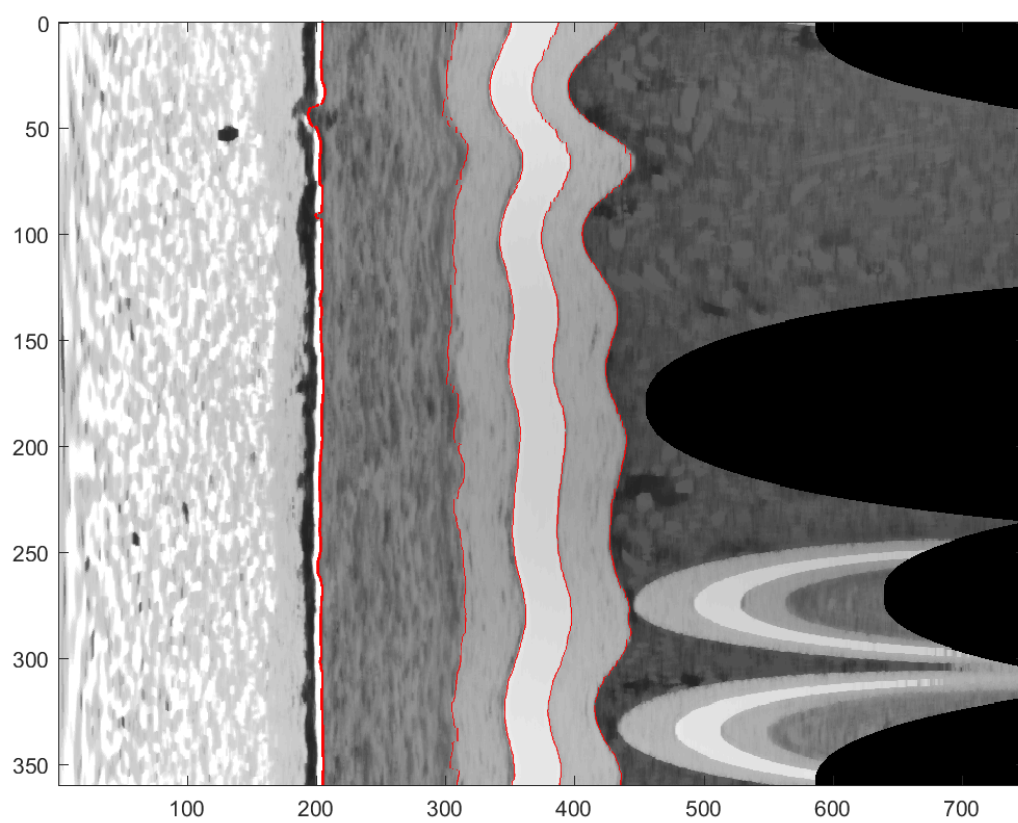
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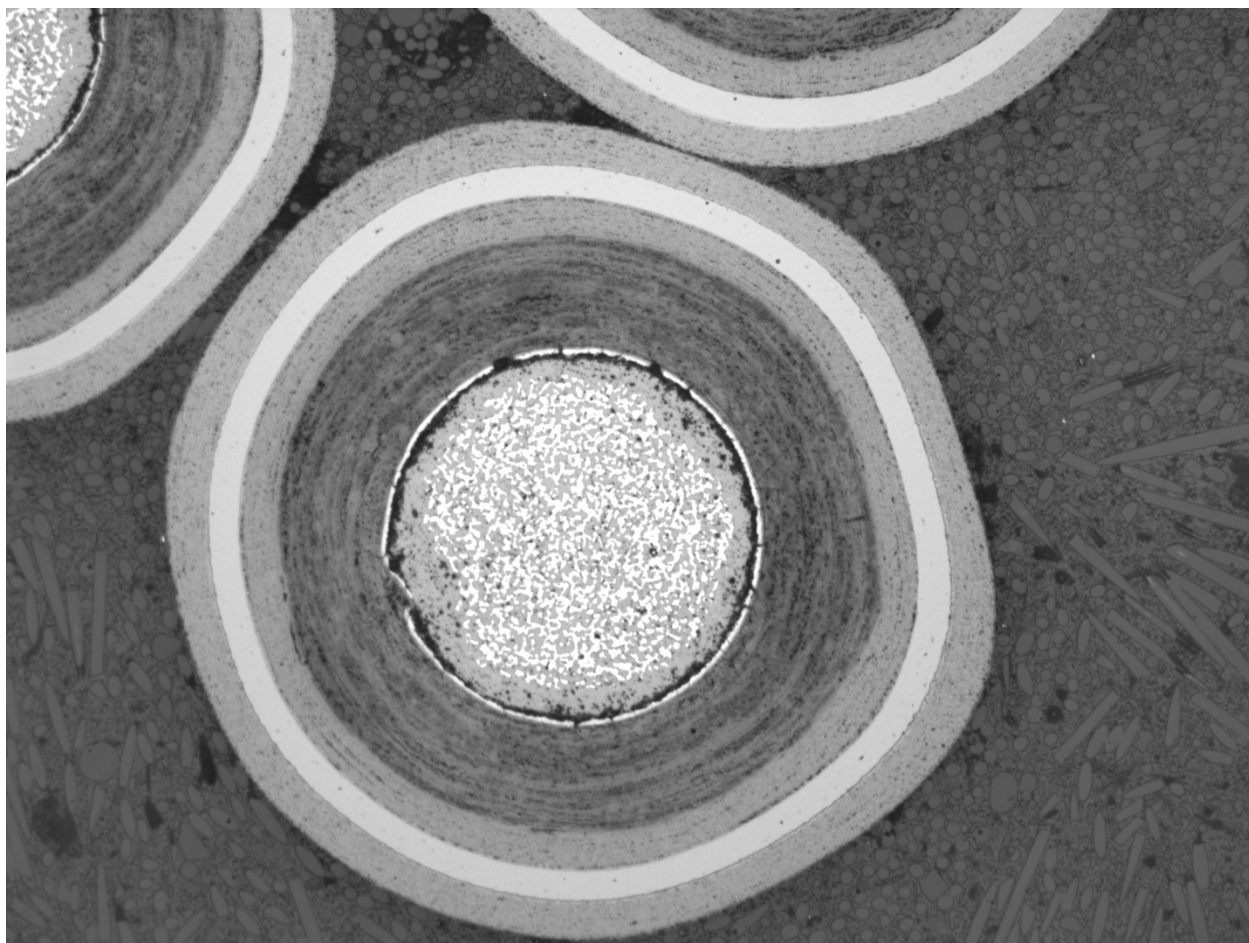
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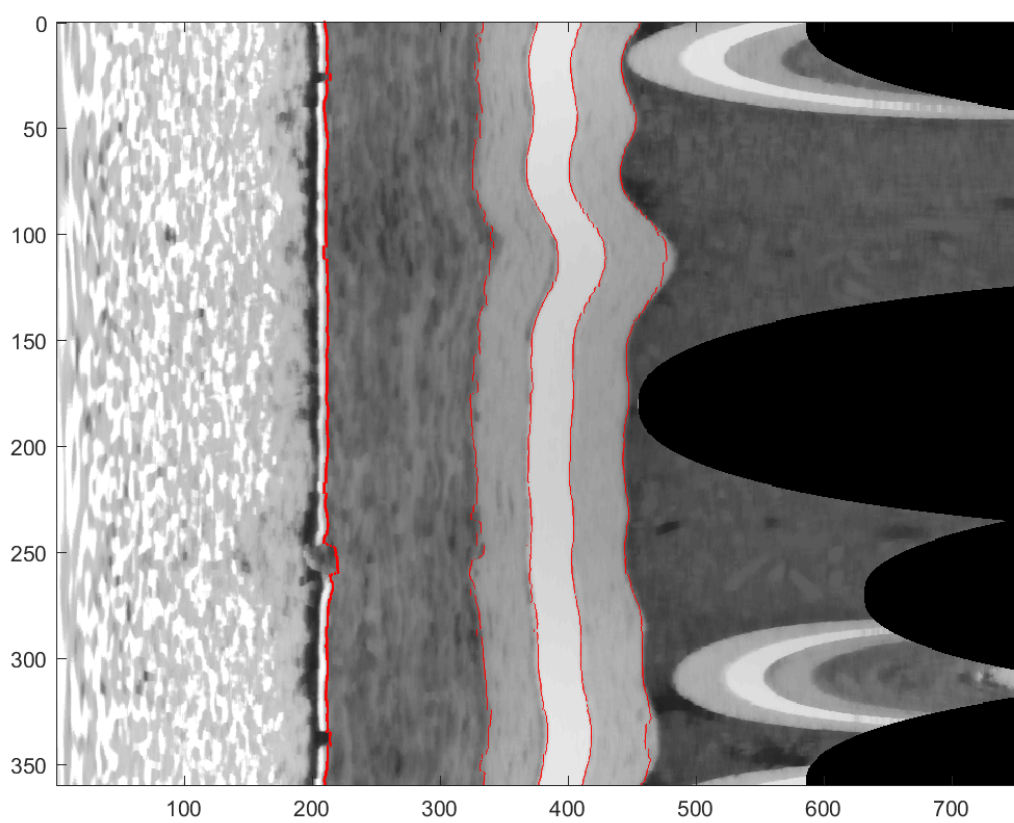
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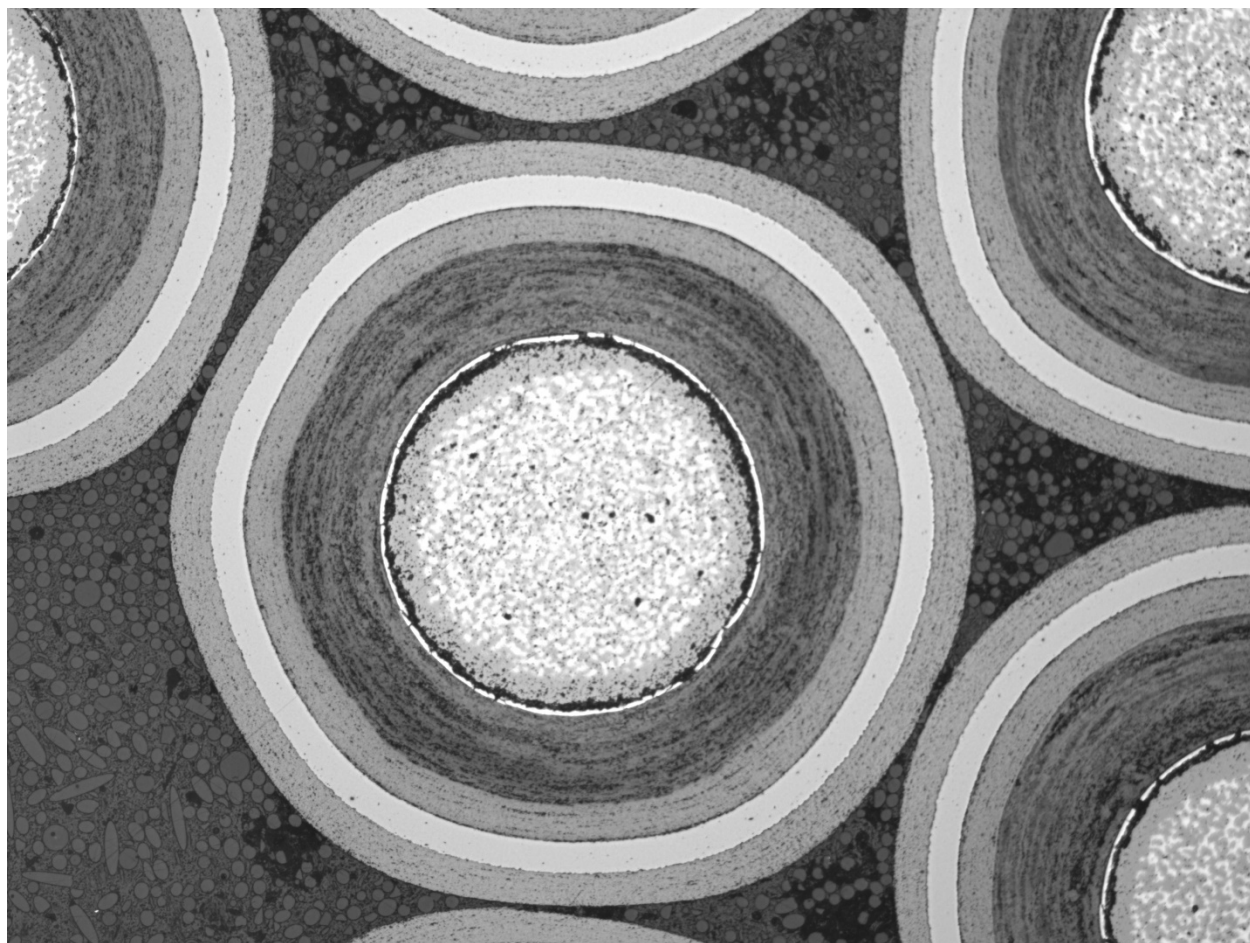


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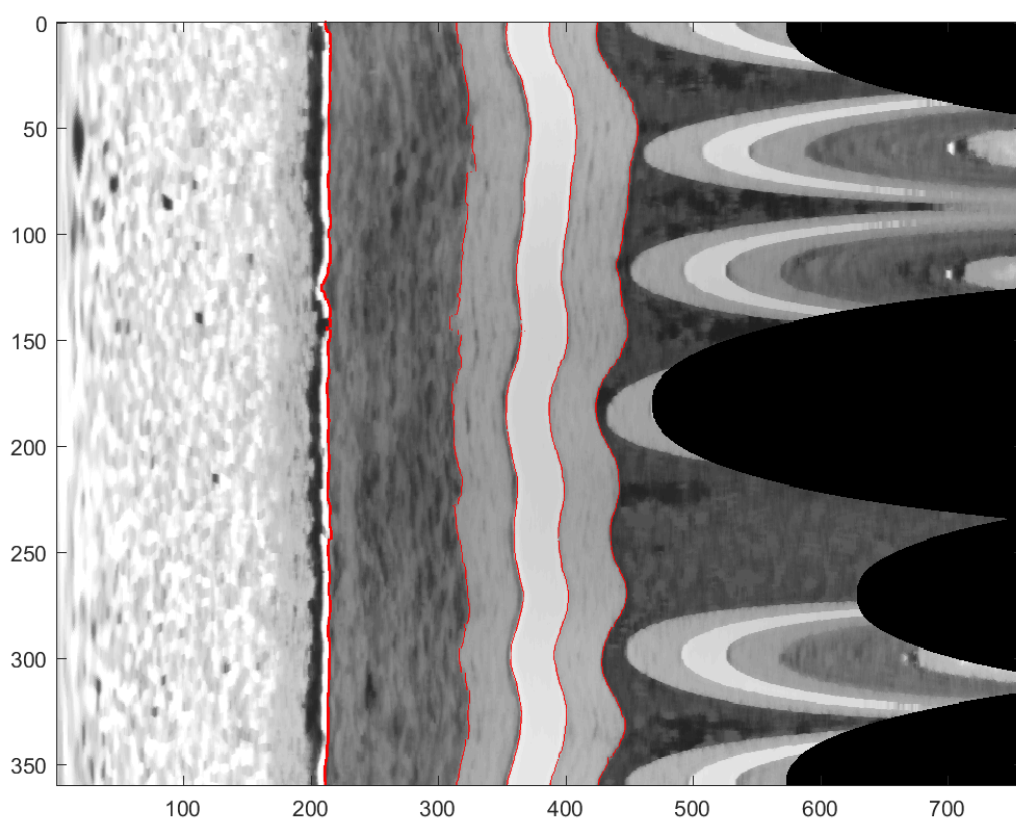
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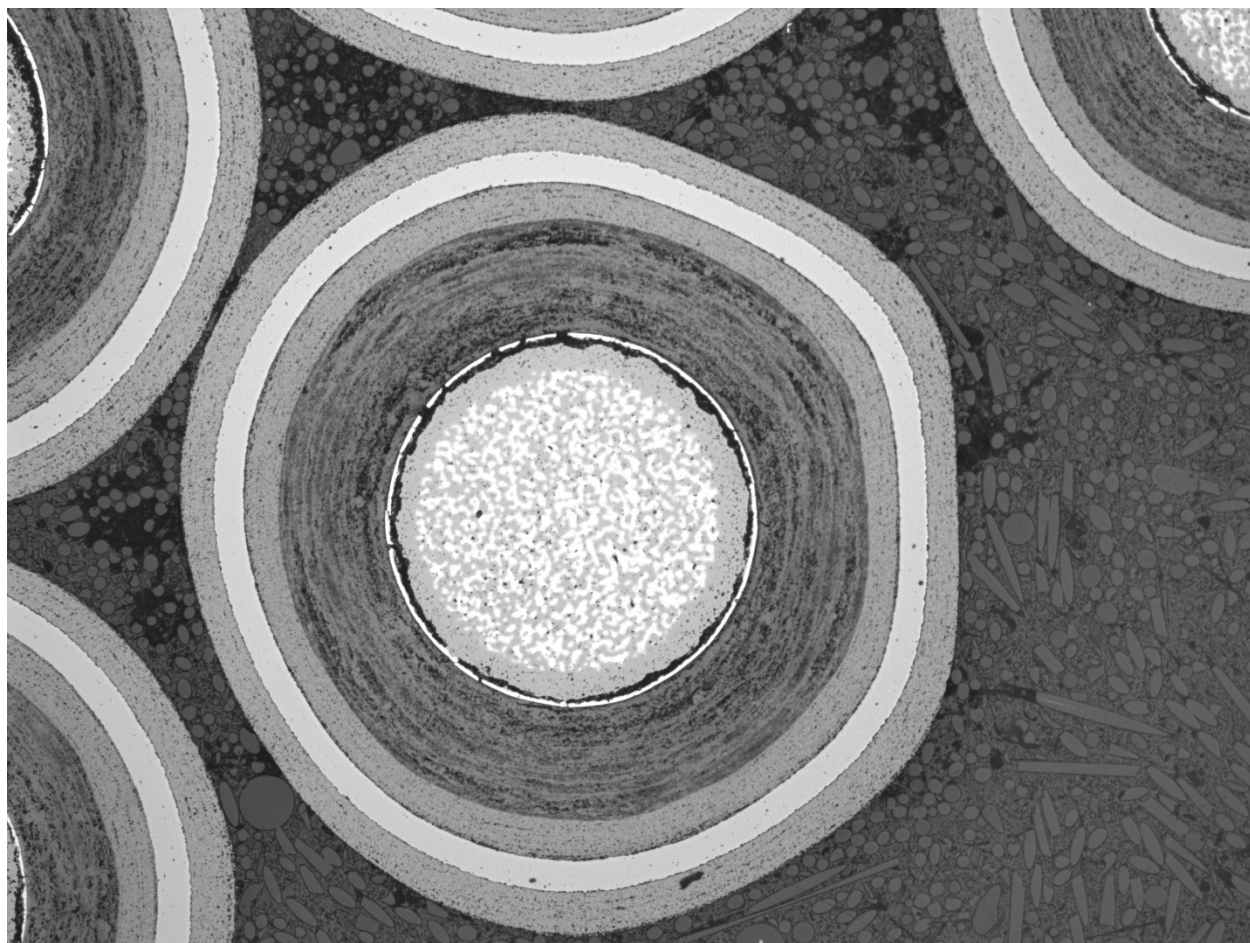


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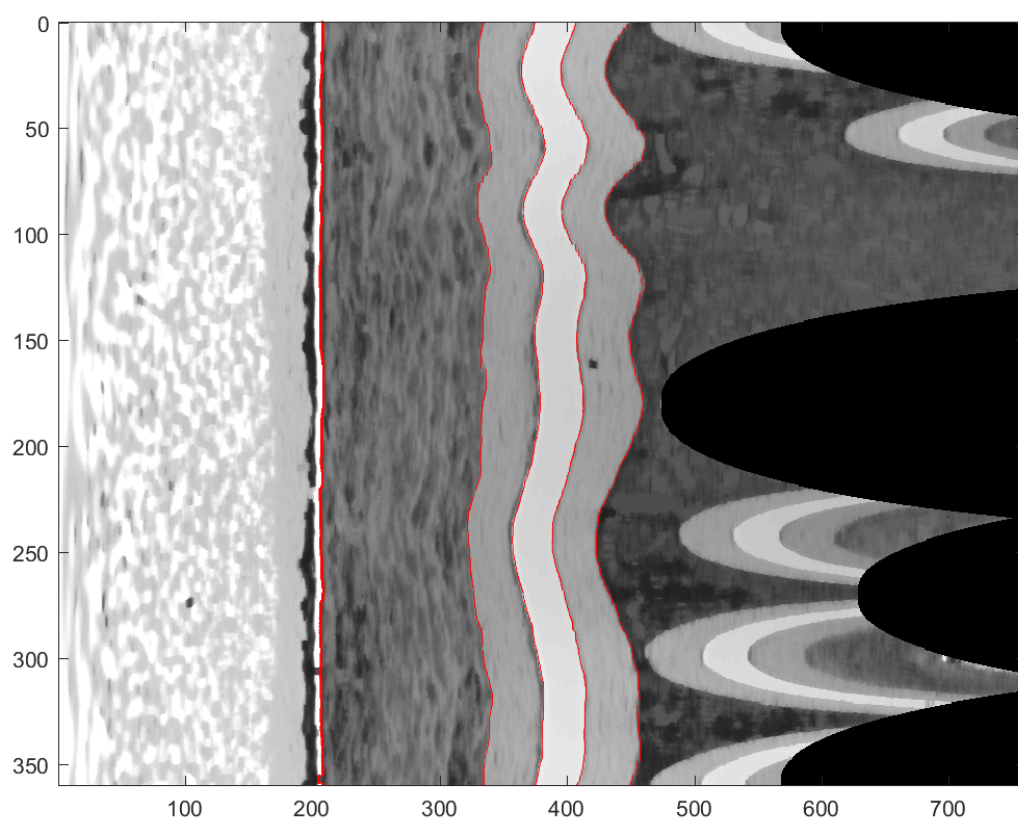




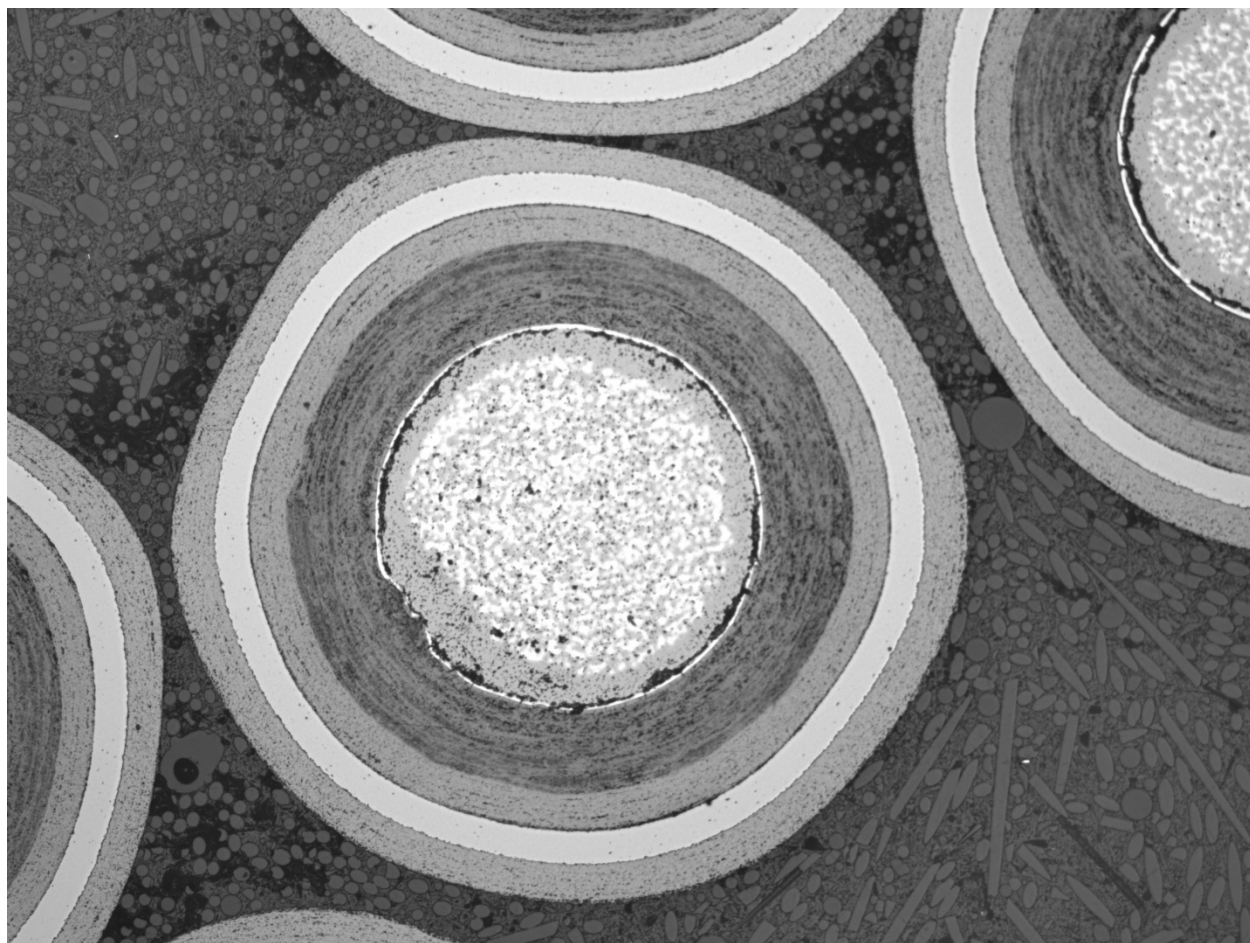
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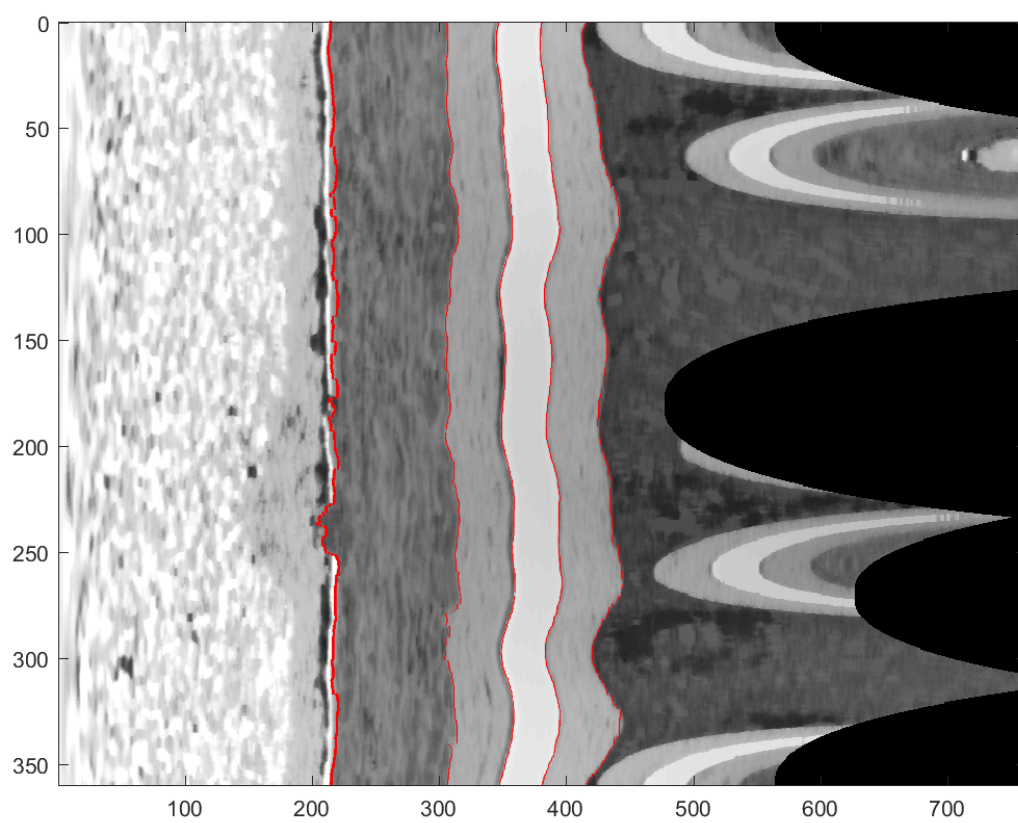
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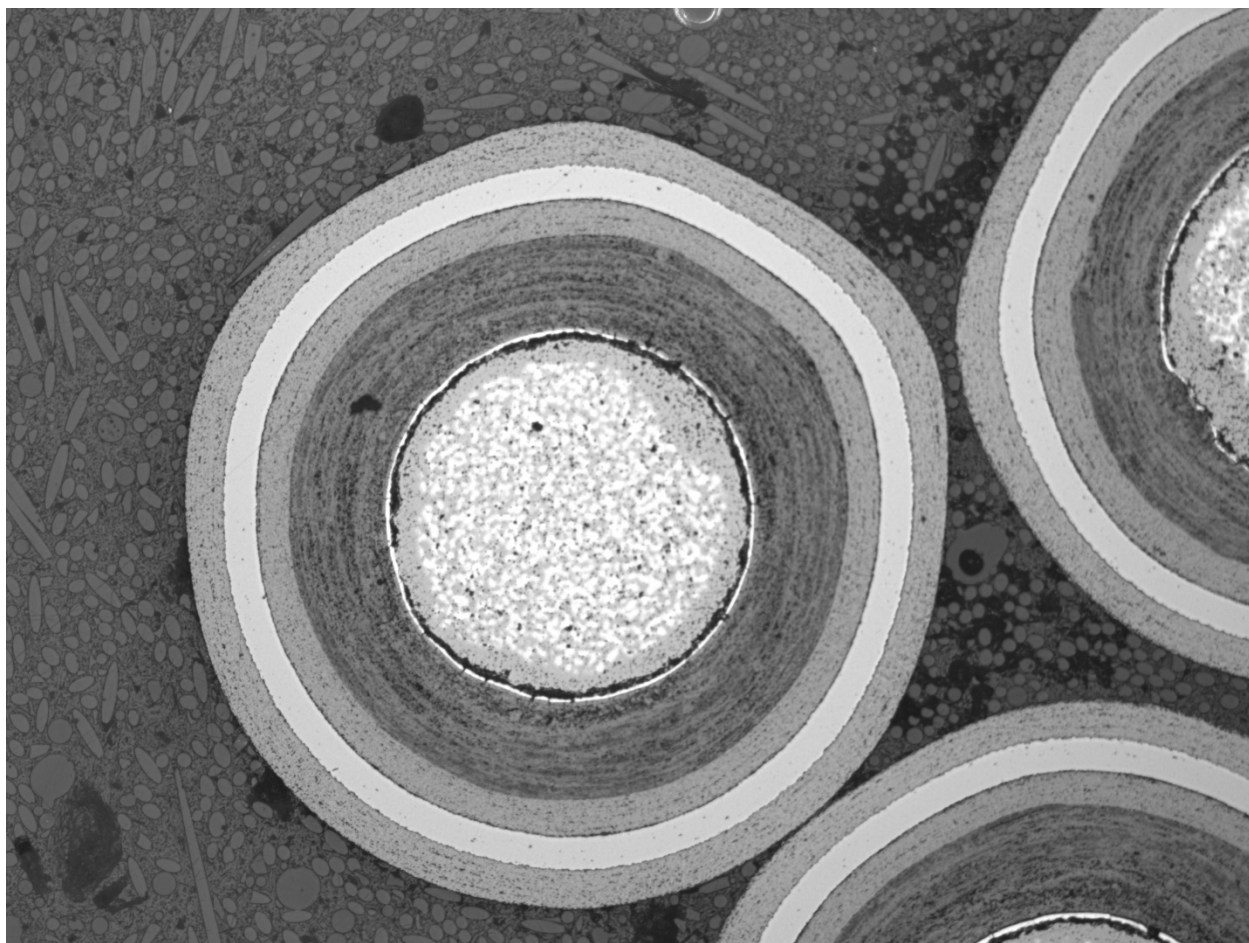
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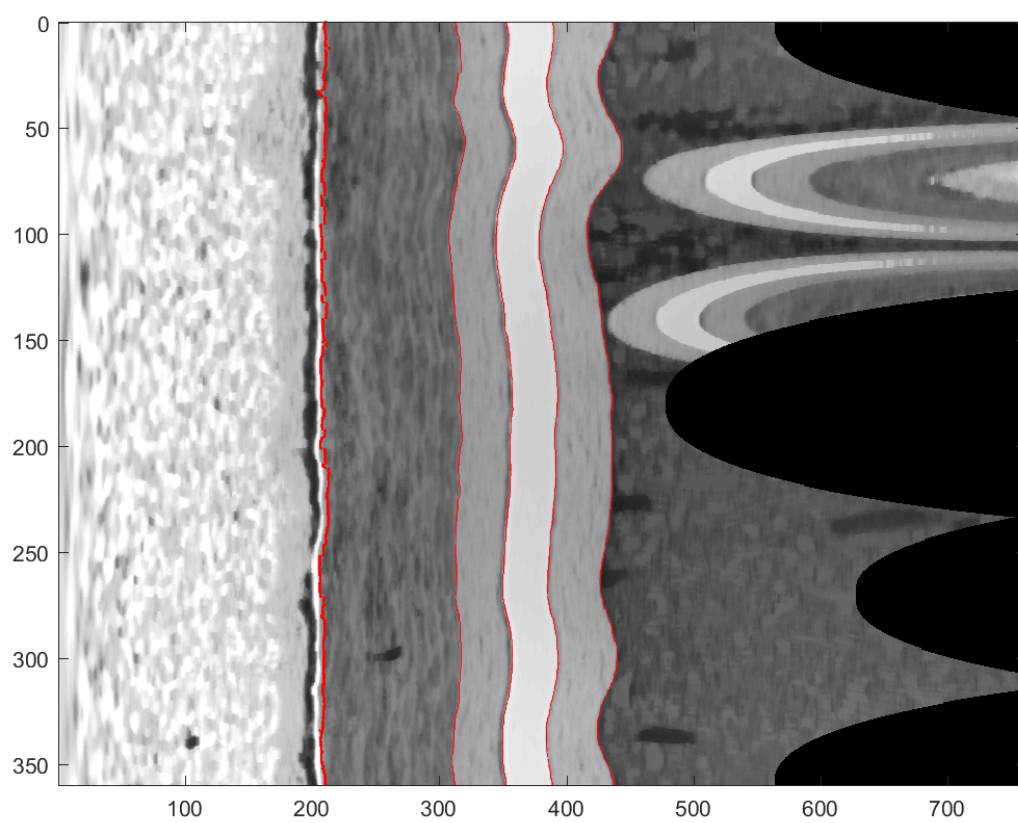
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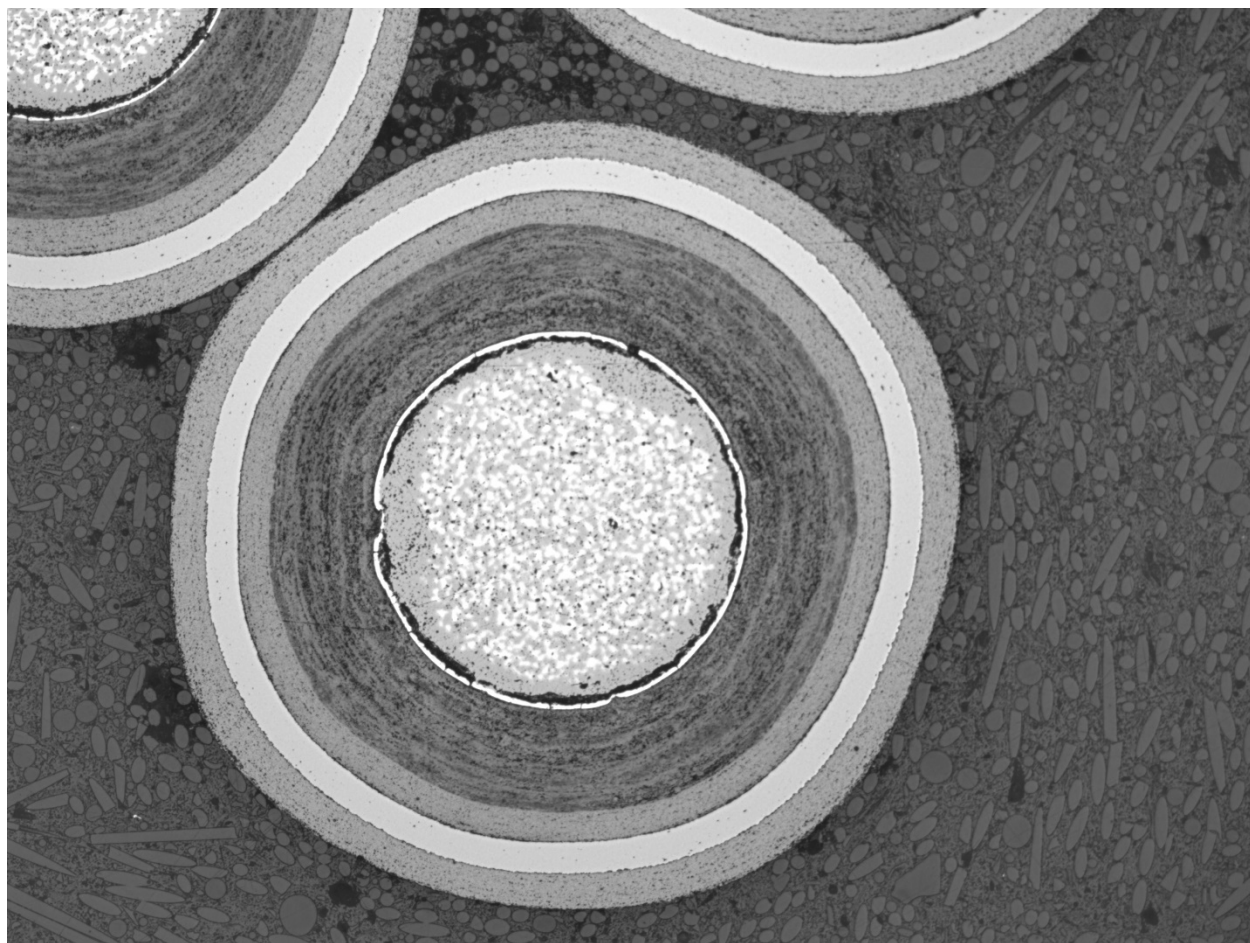


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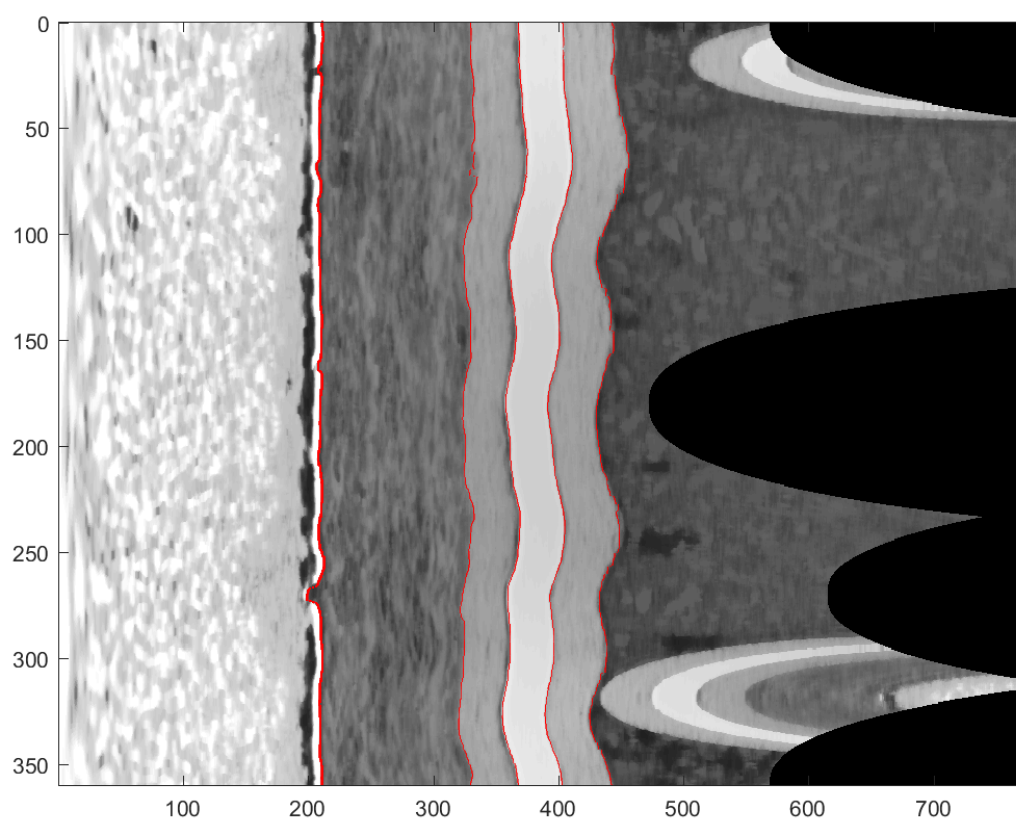


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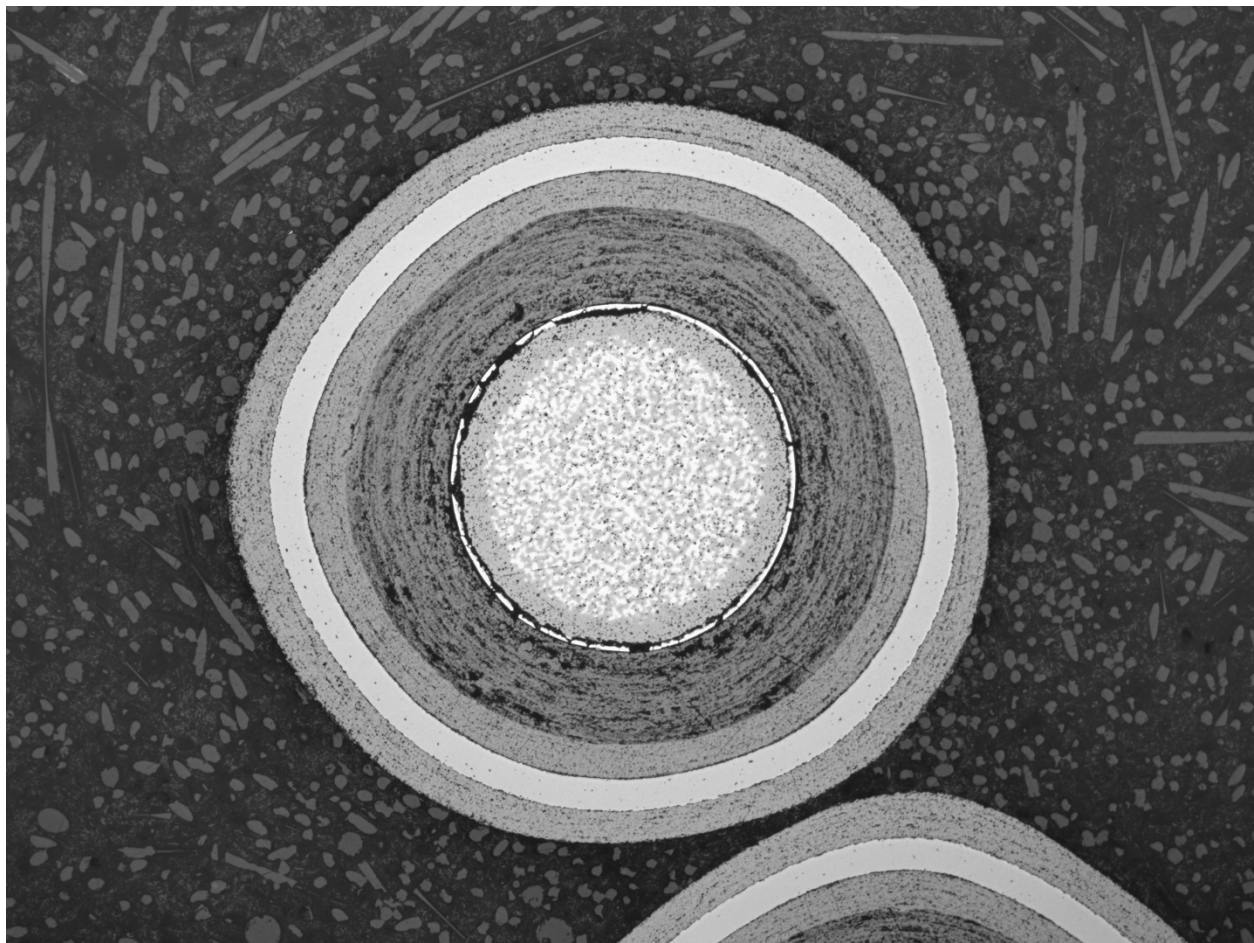




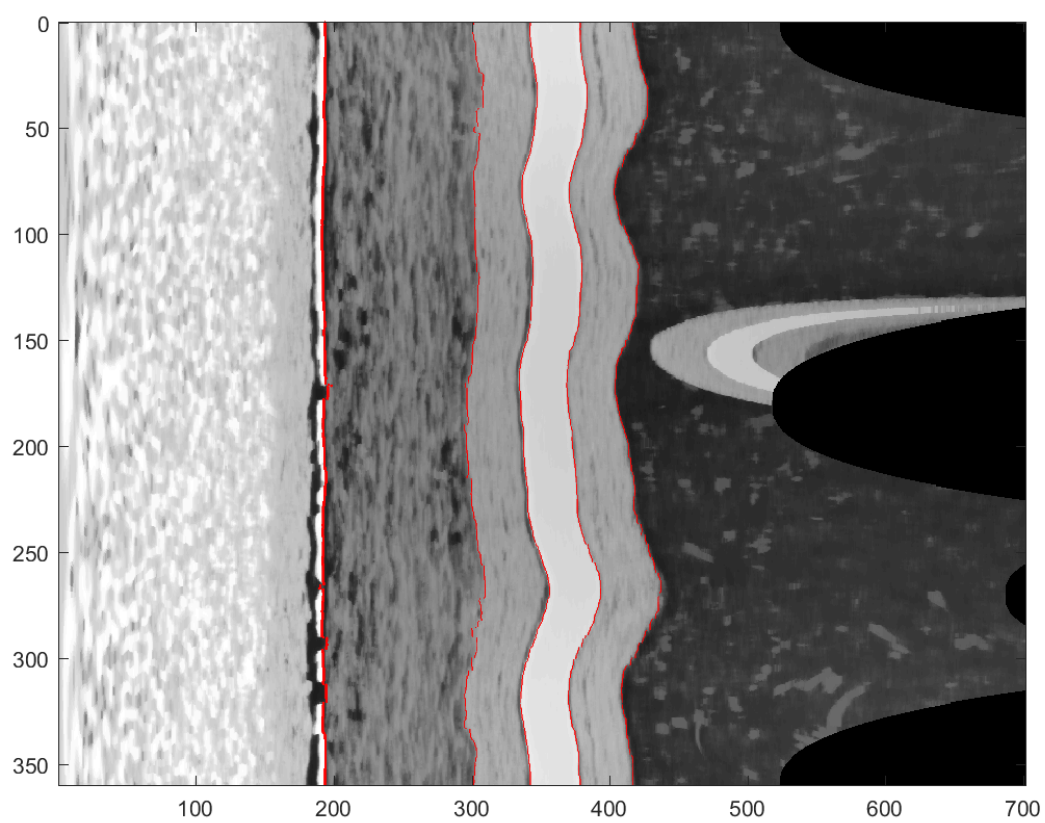
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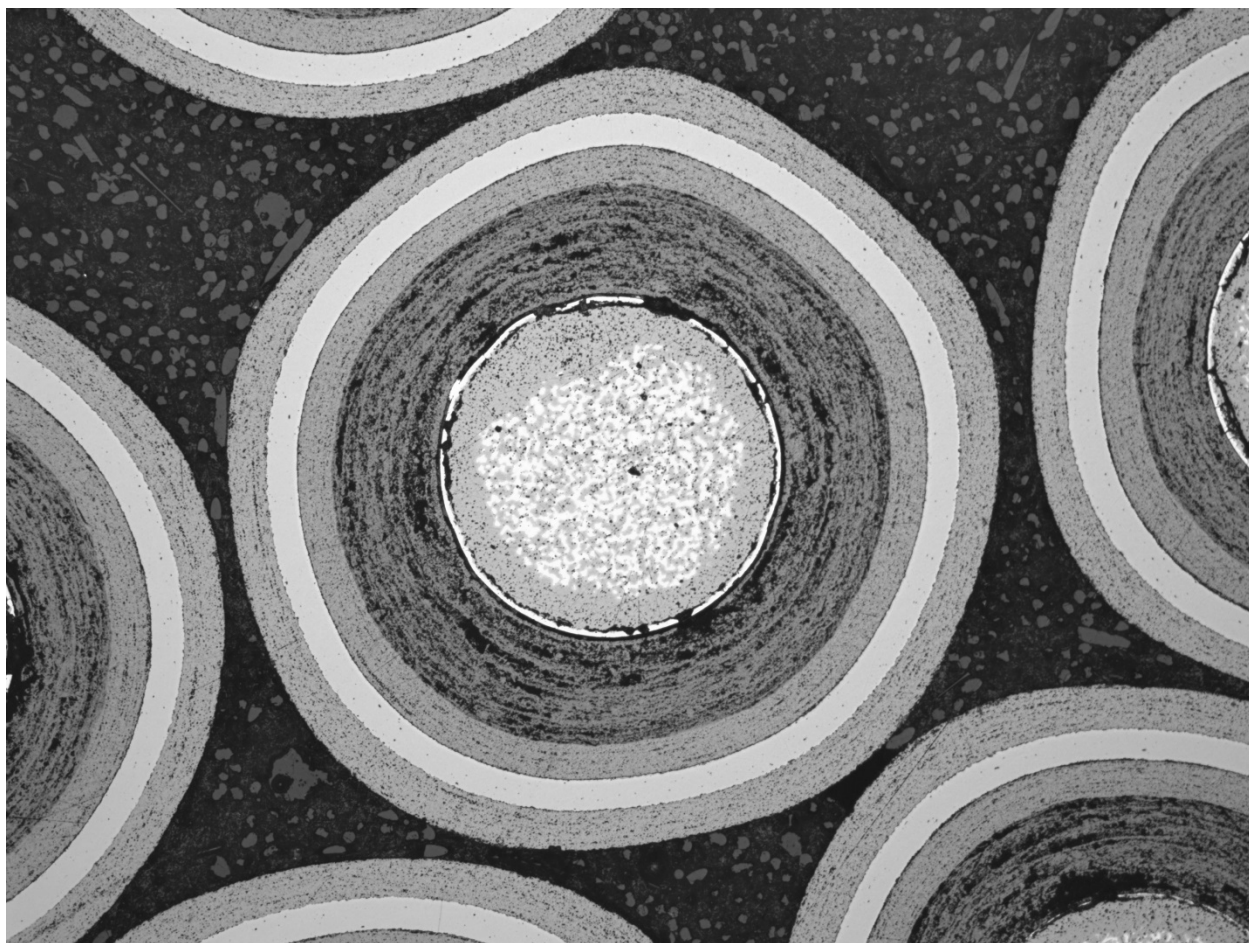
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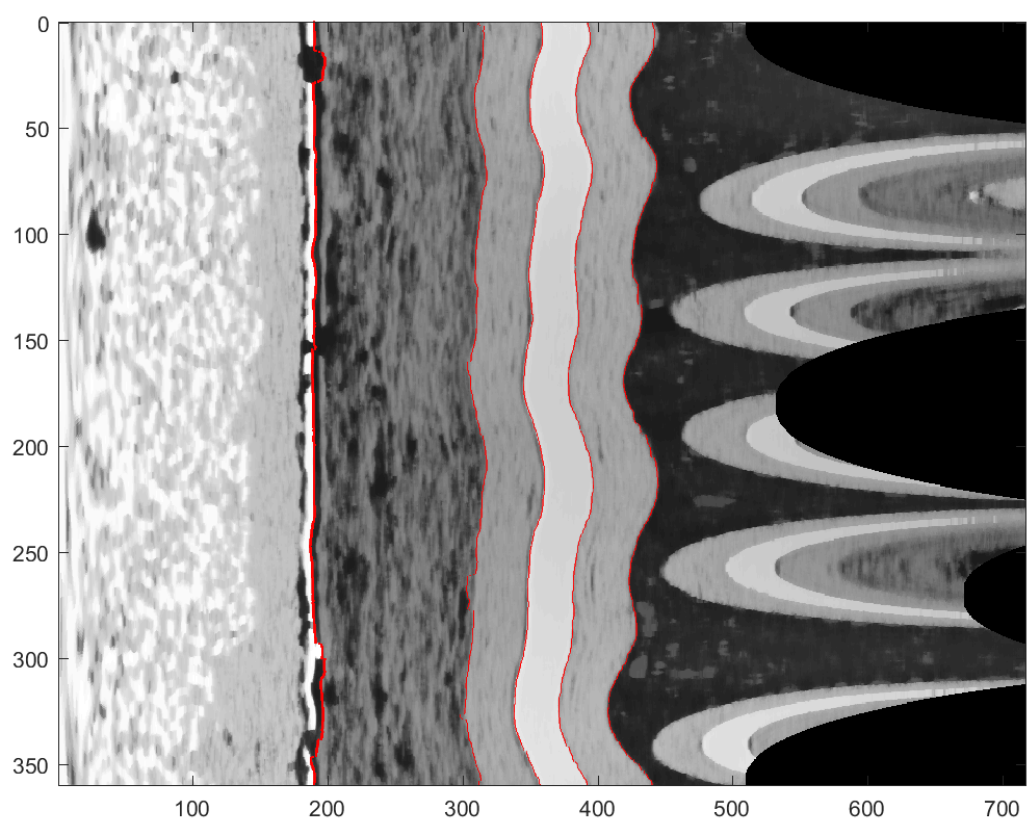
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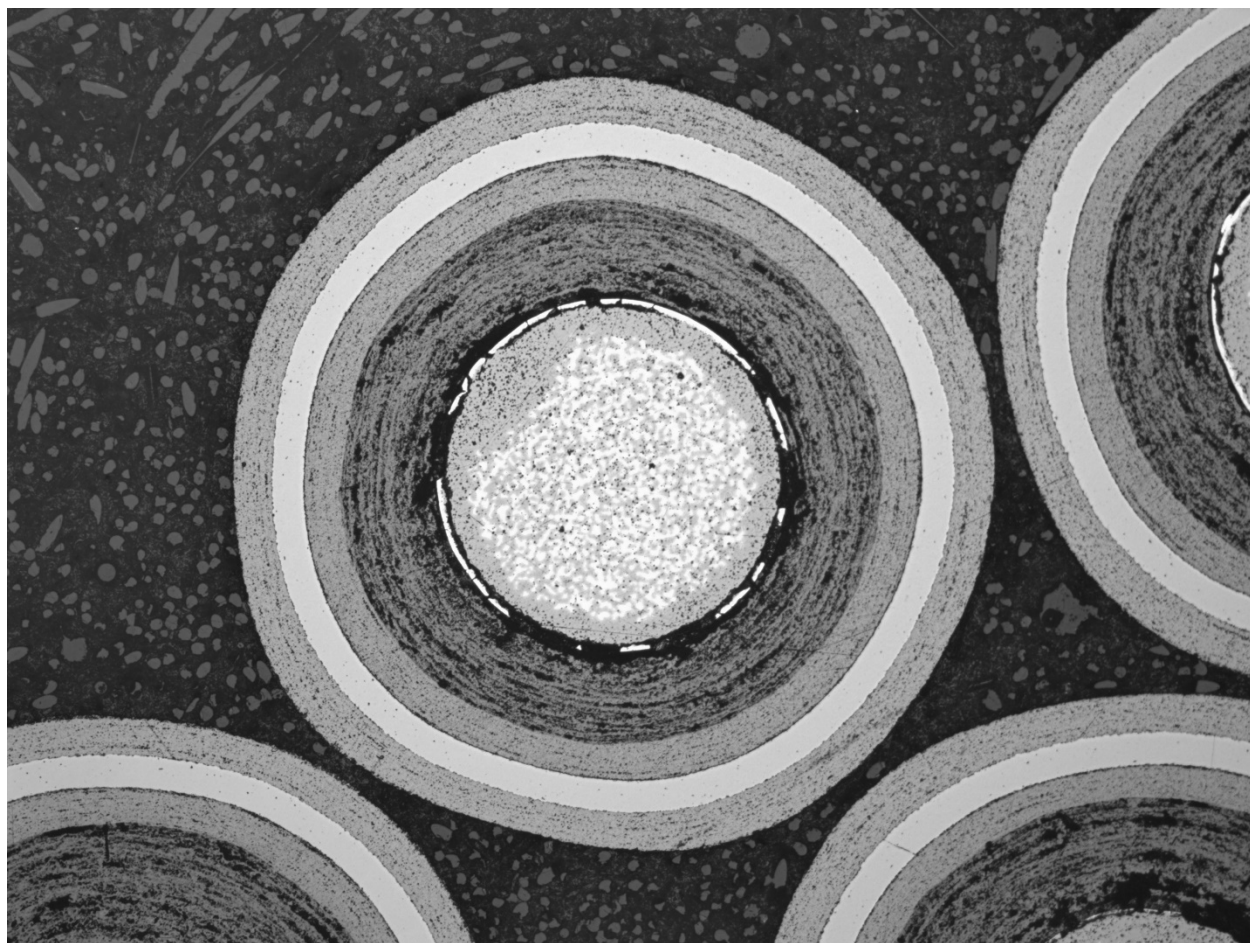


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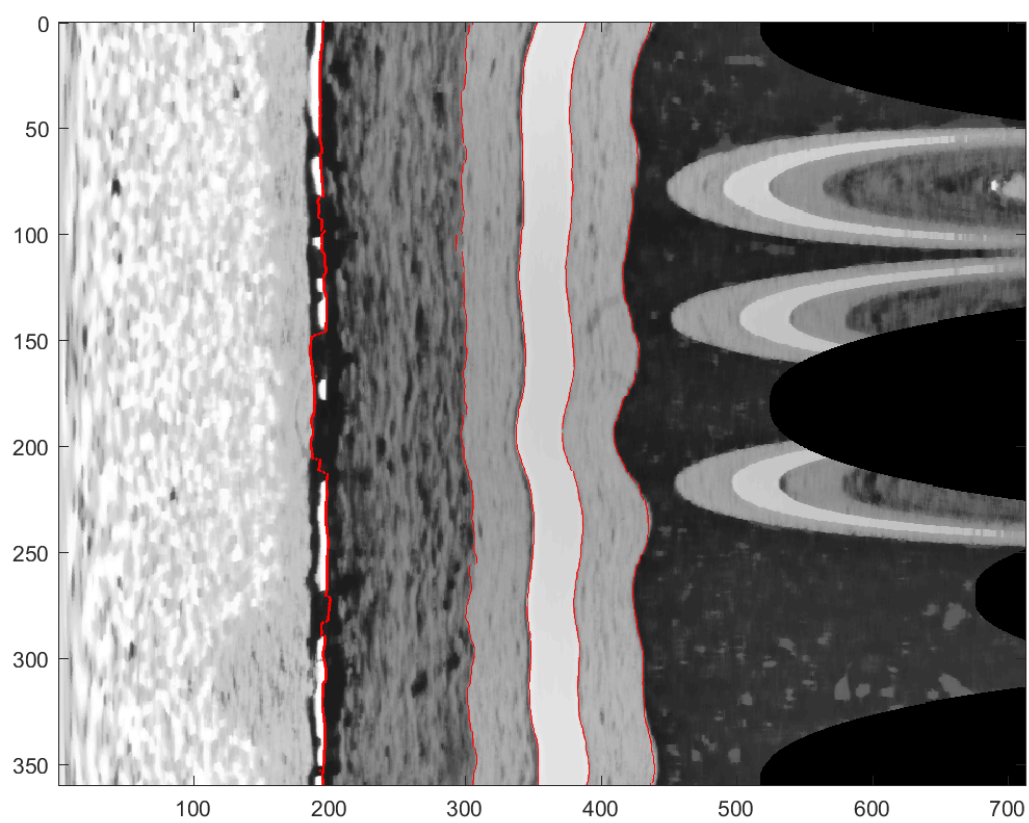
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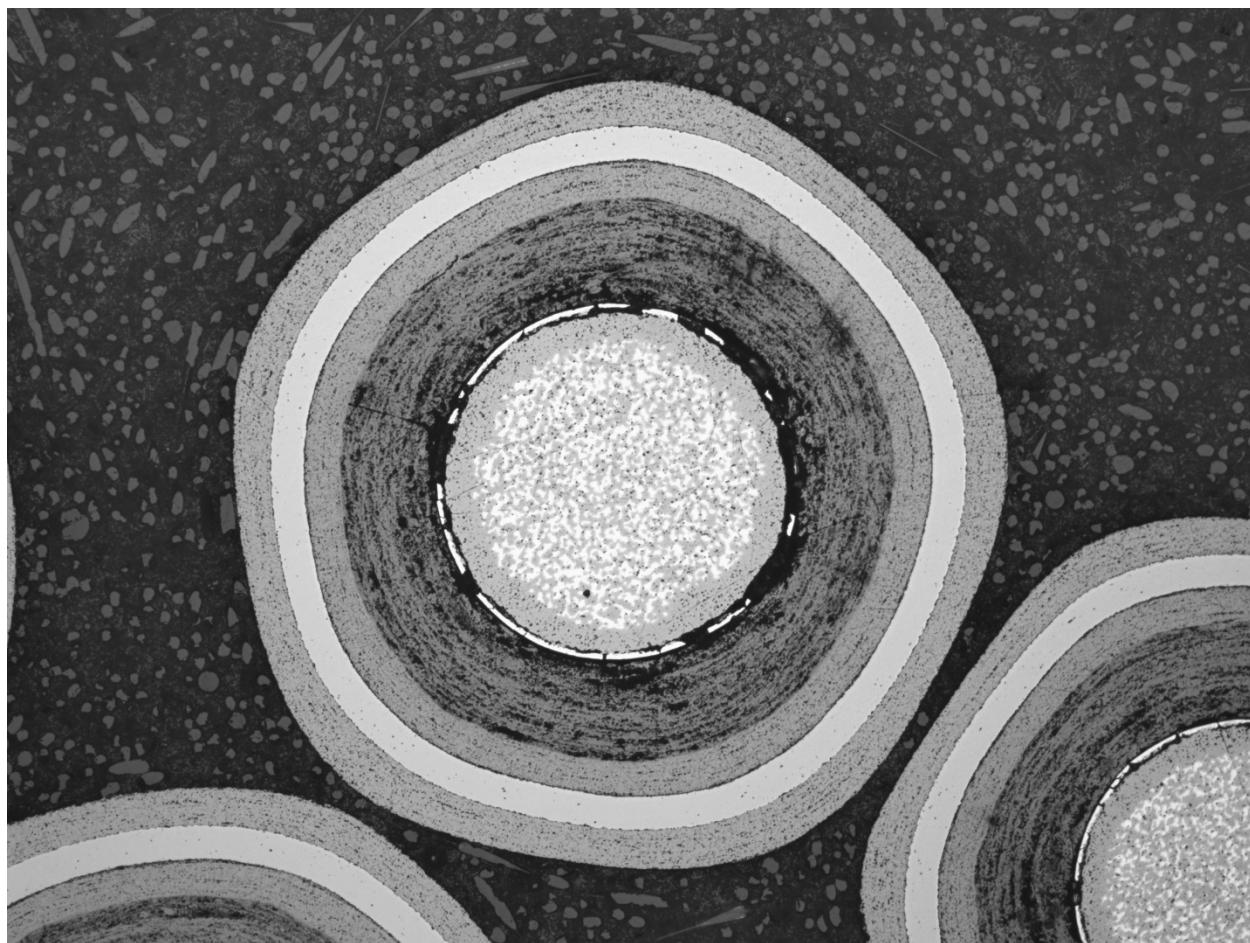


P16082301N004

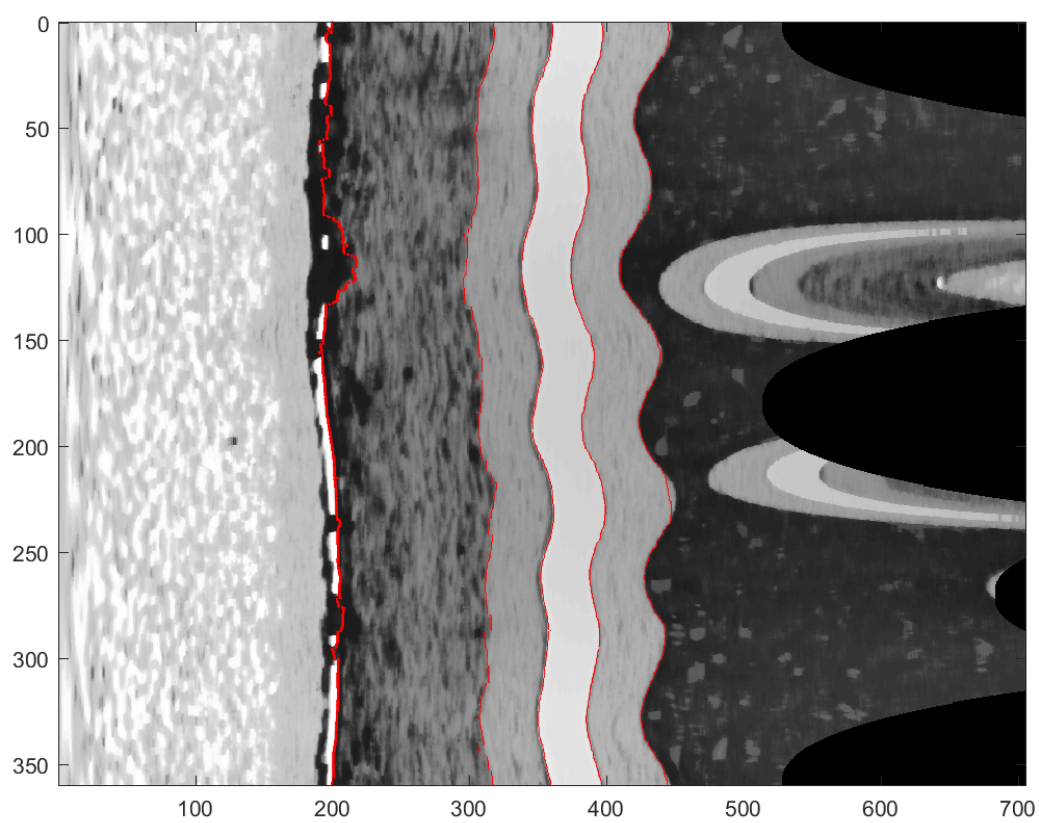




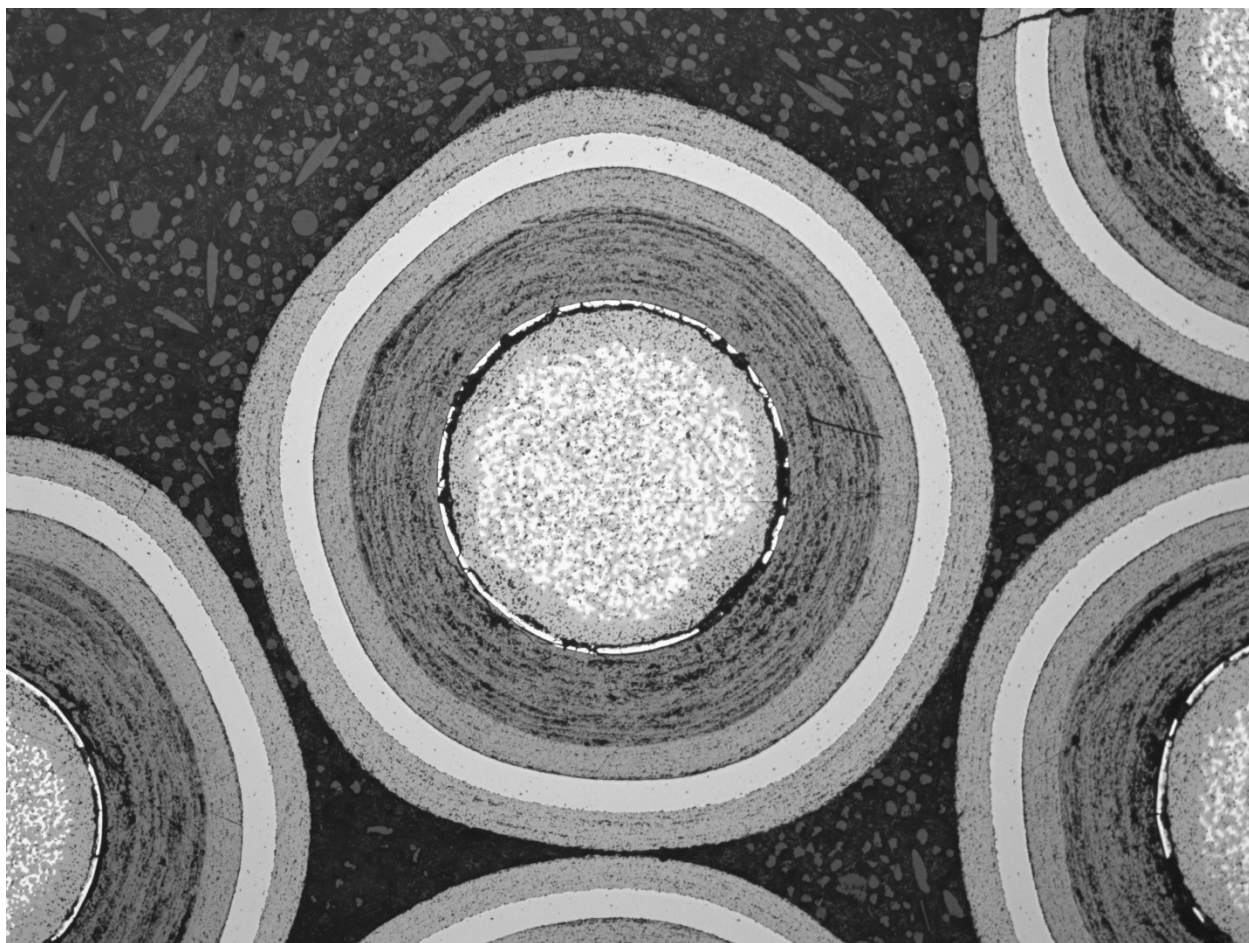
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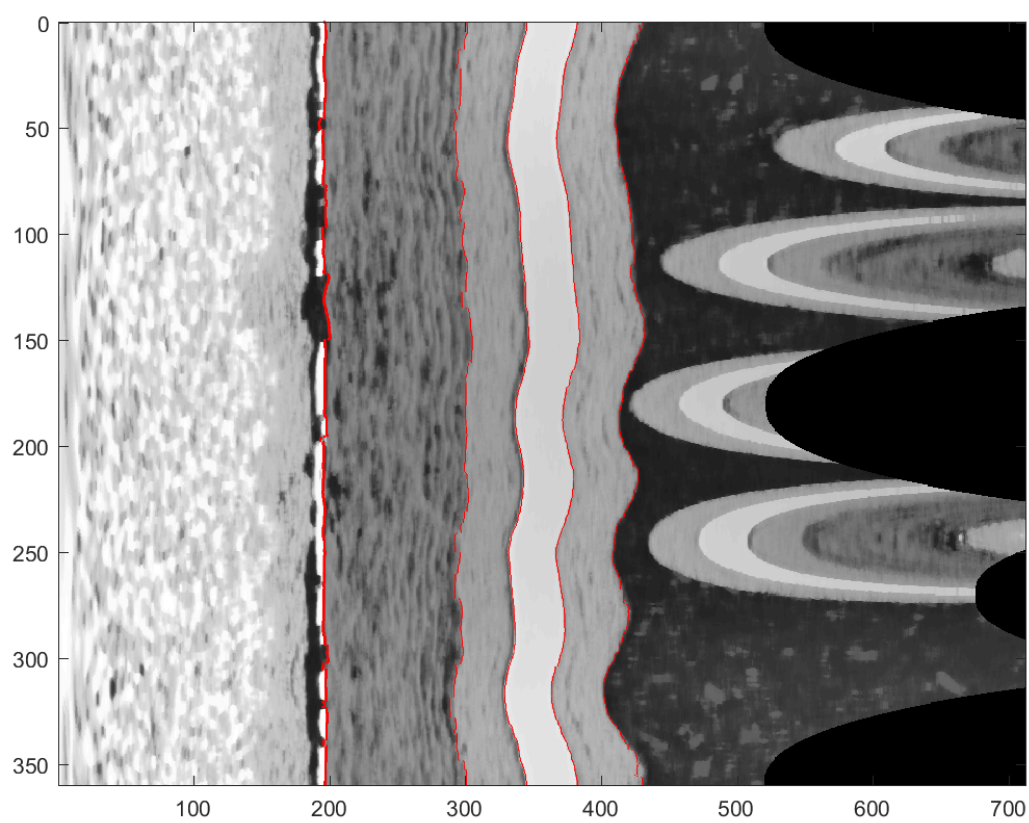
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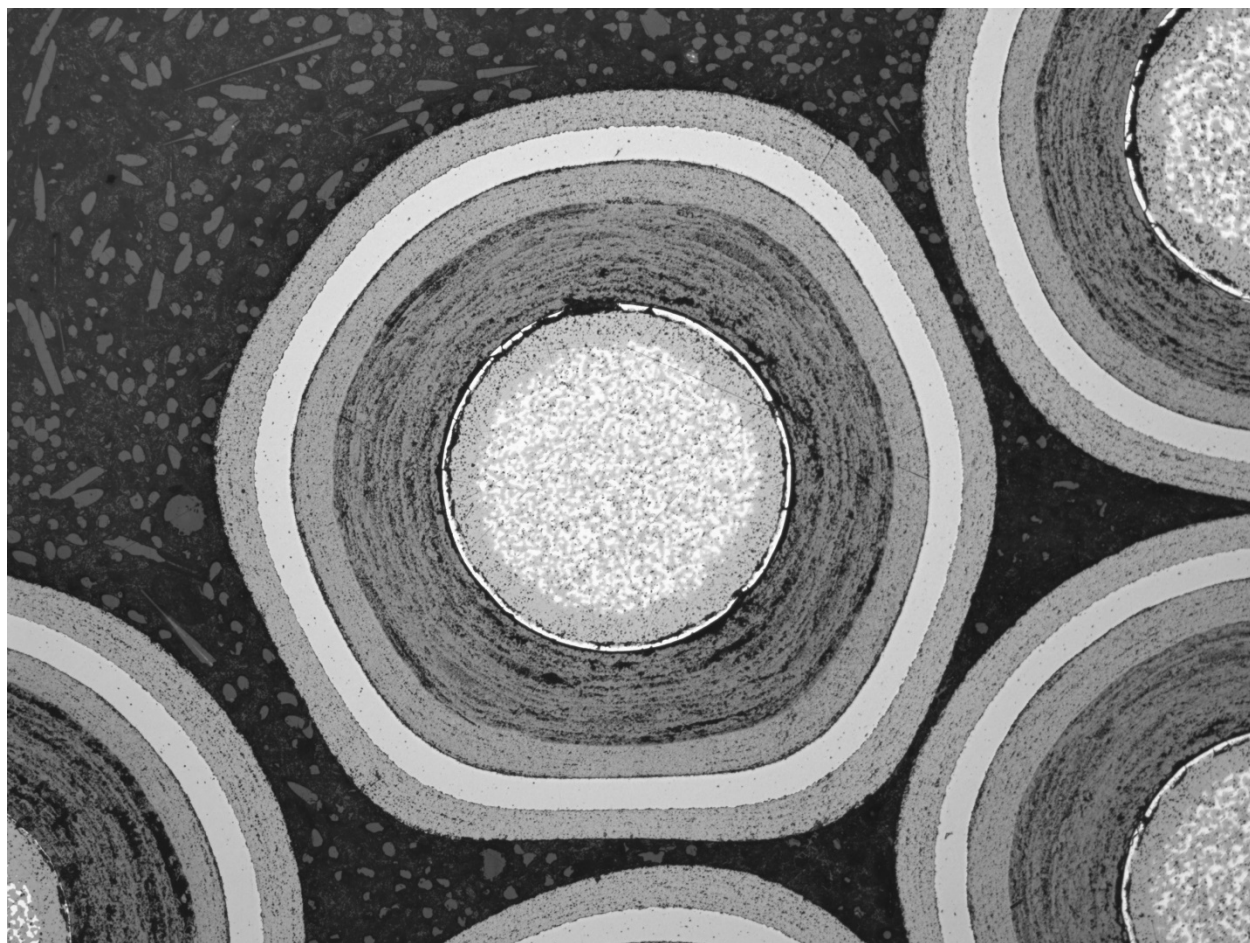
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P16082301N006

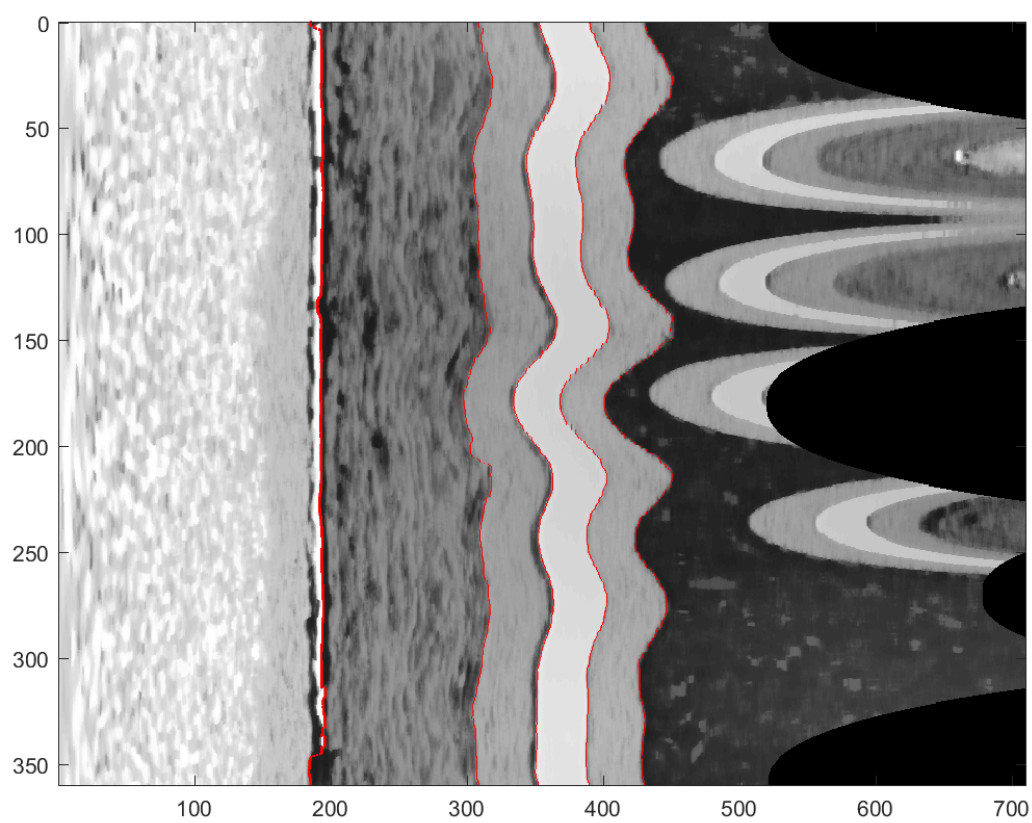


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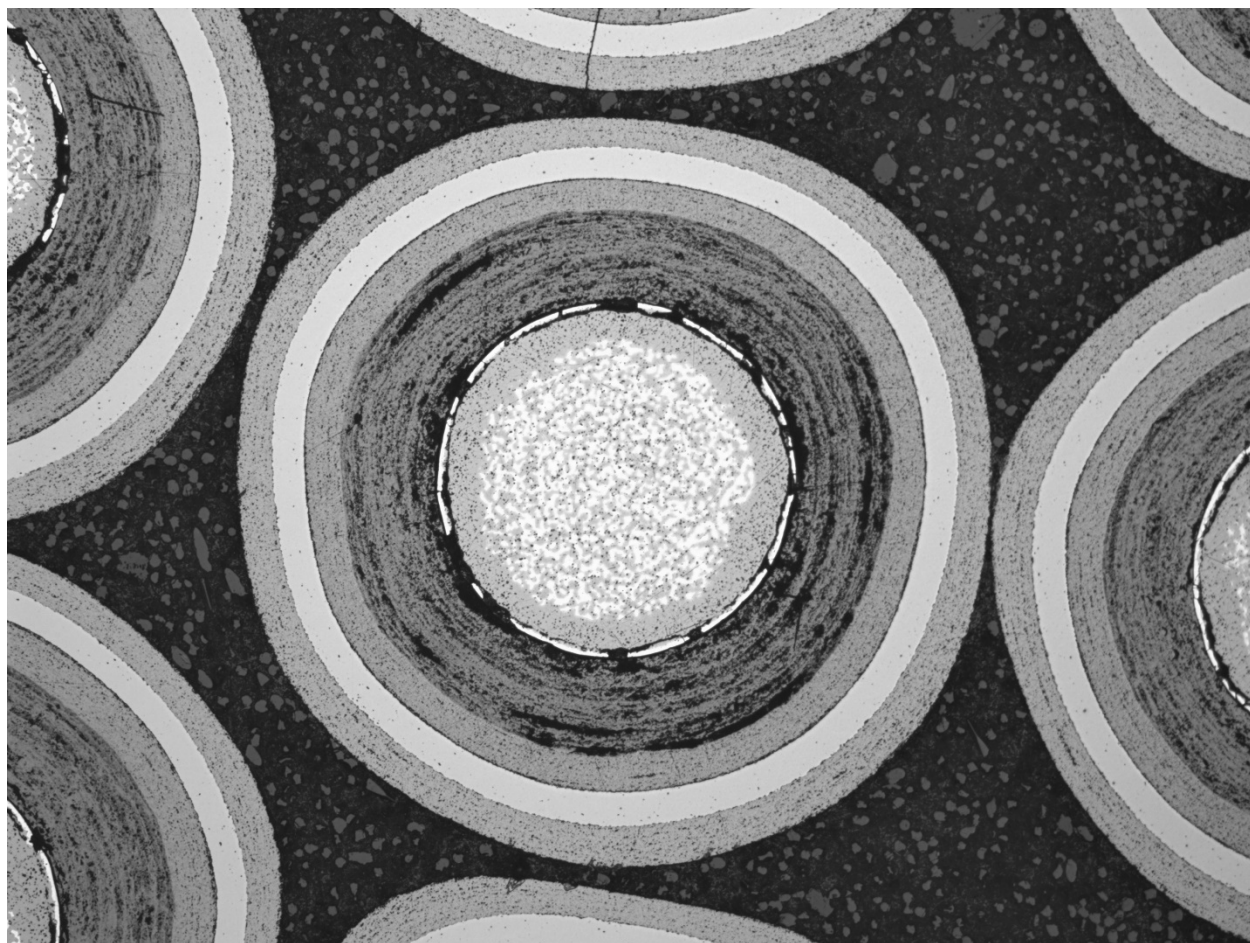
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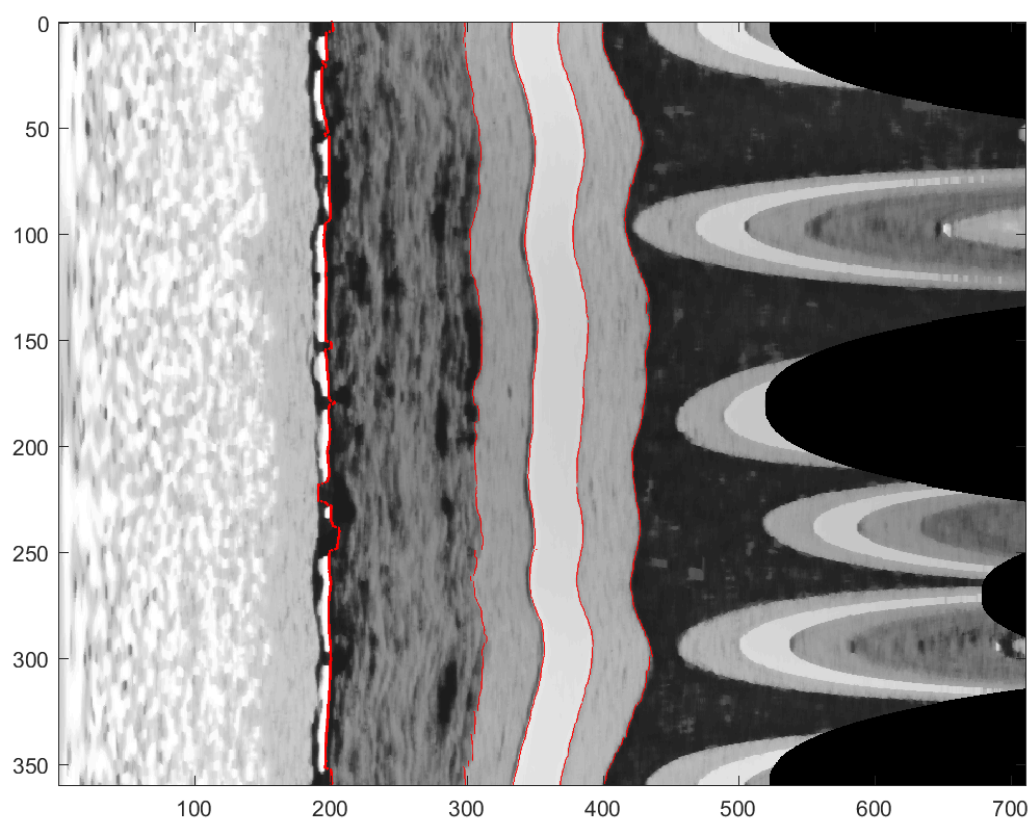


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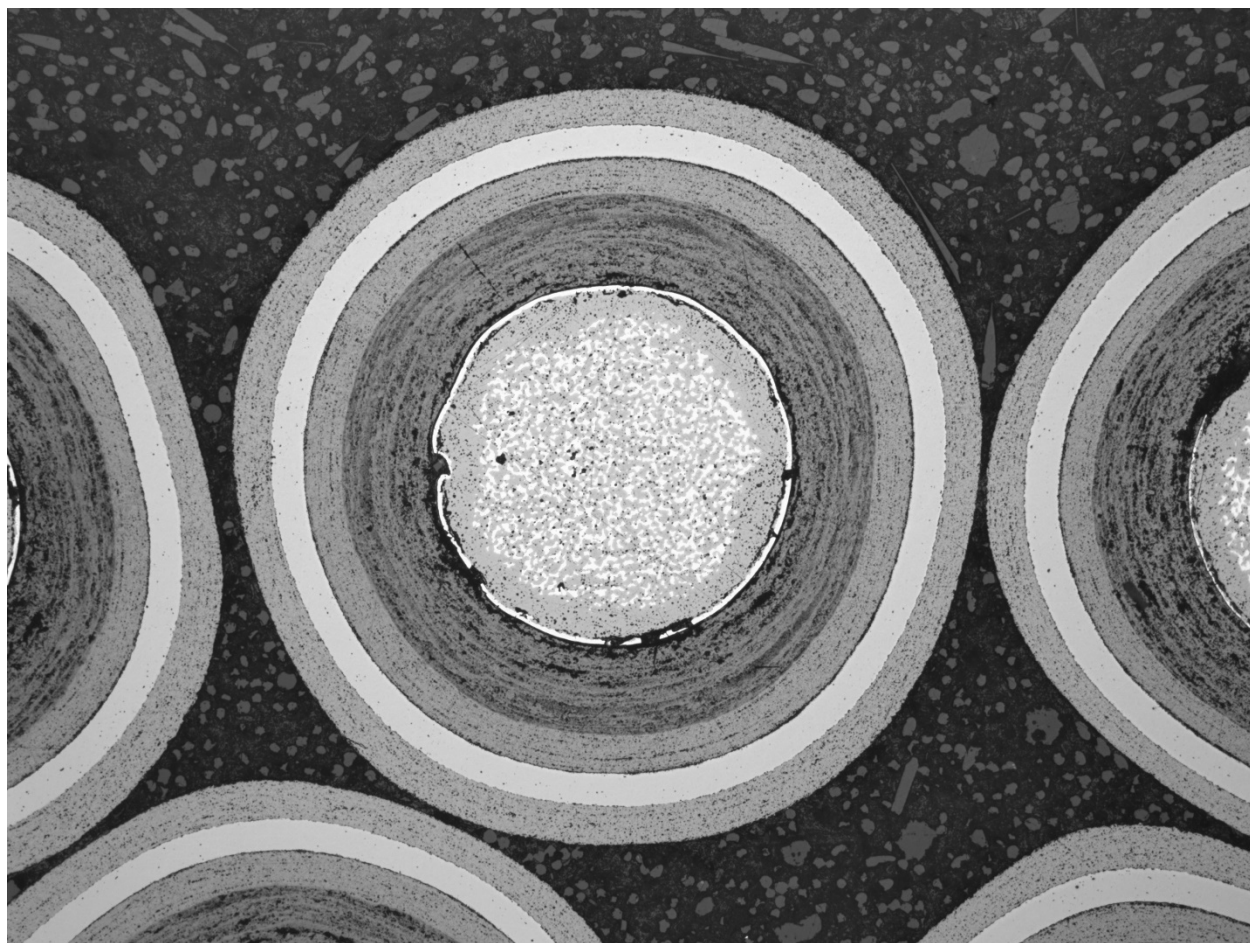




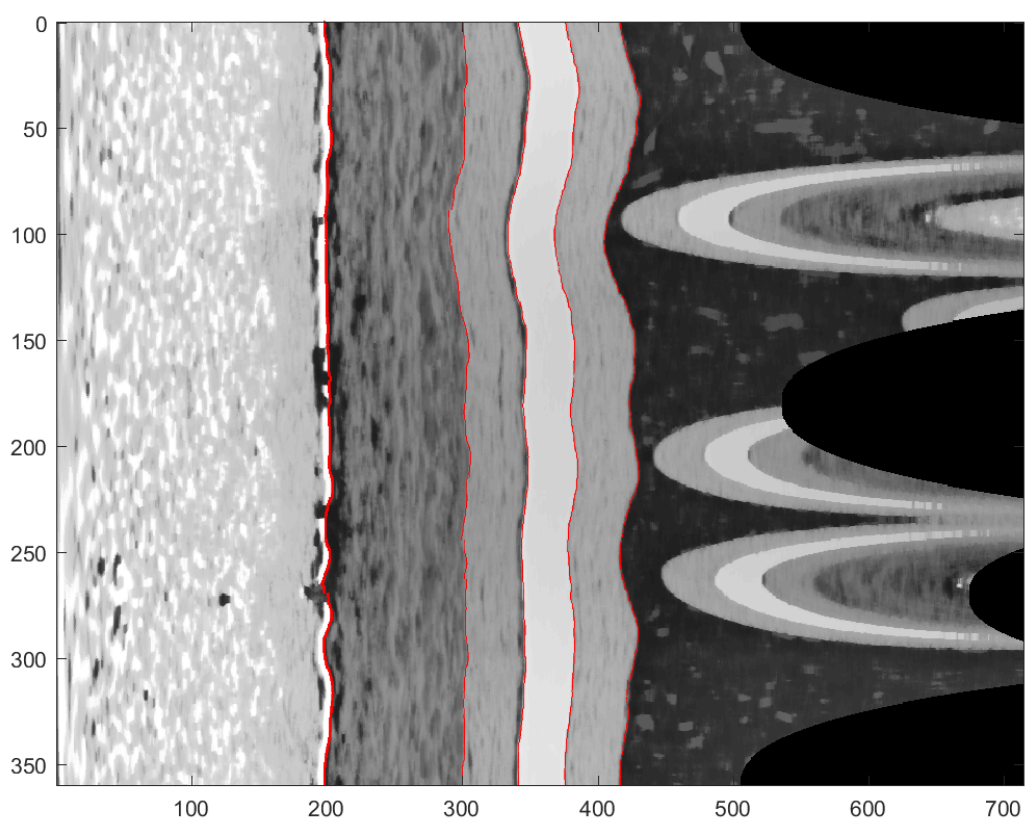
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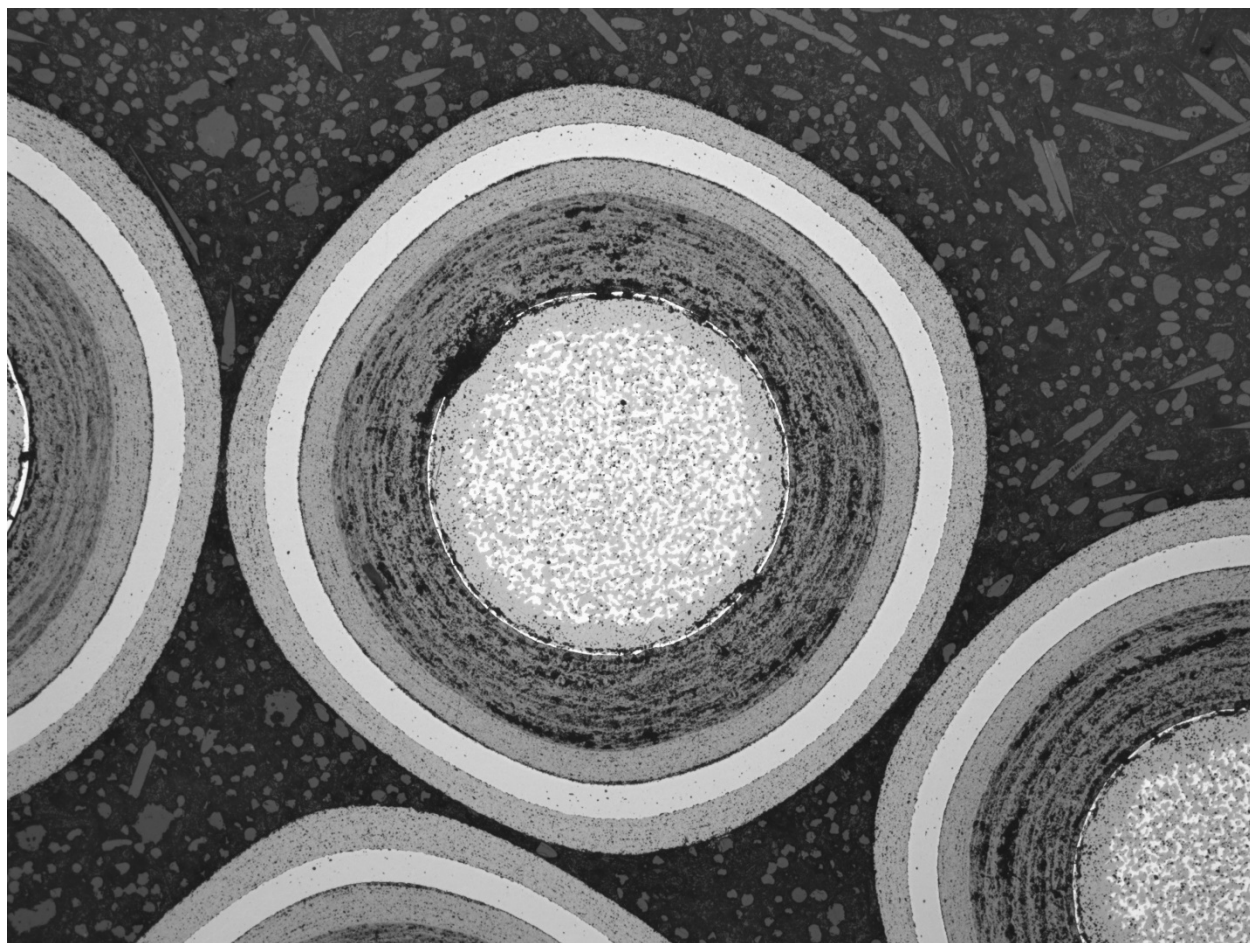
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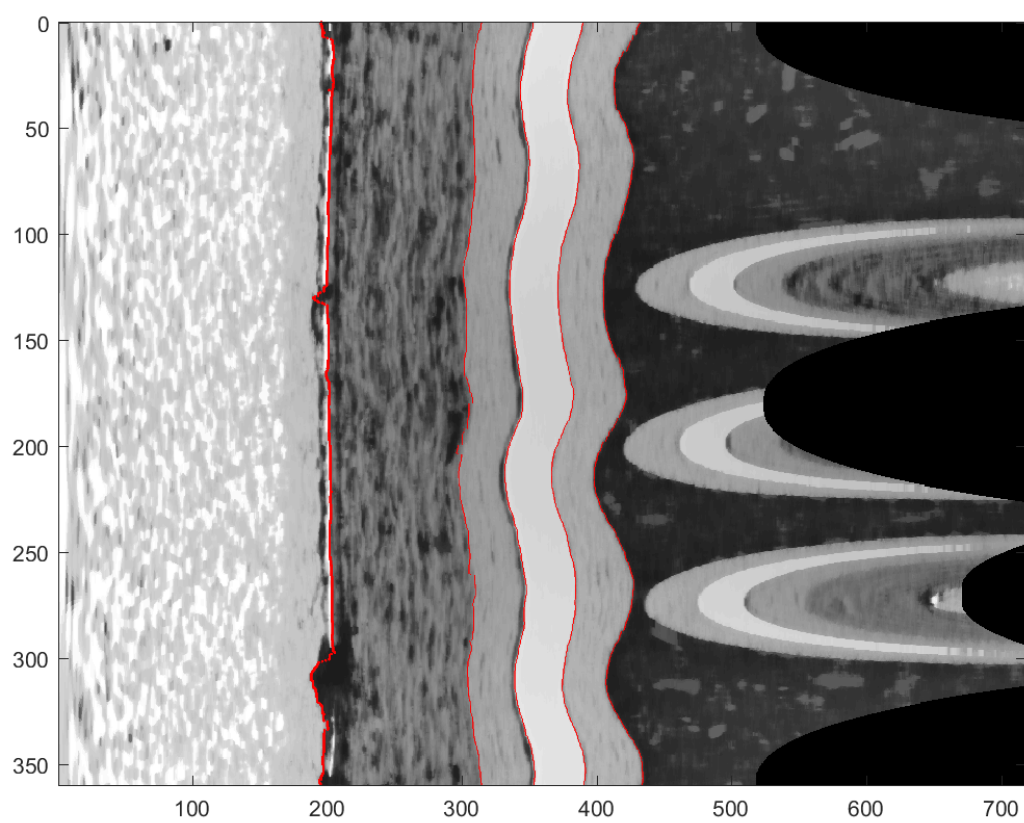
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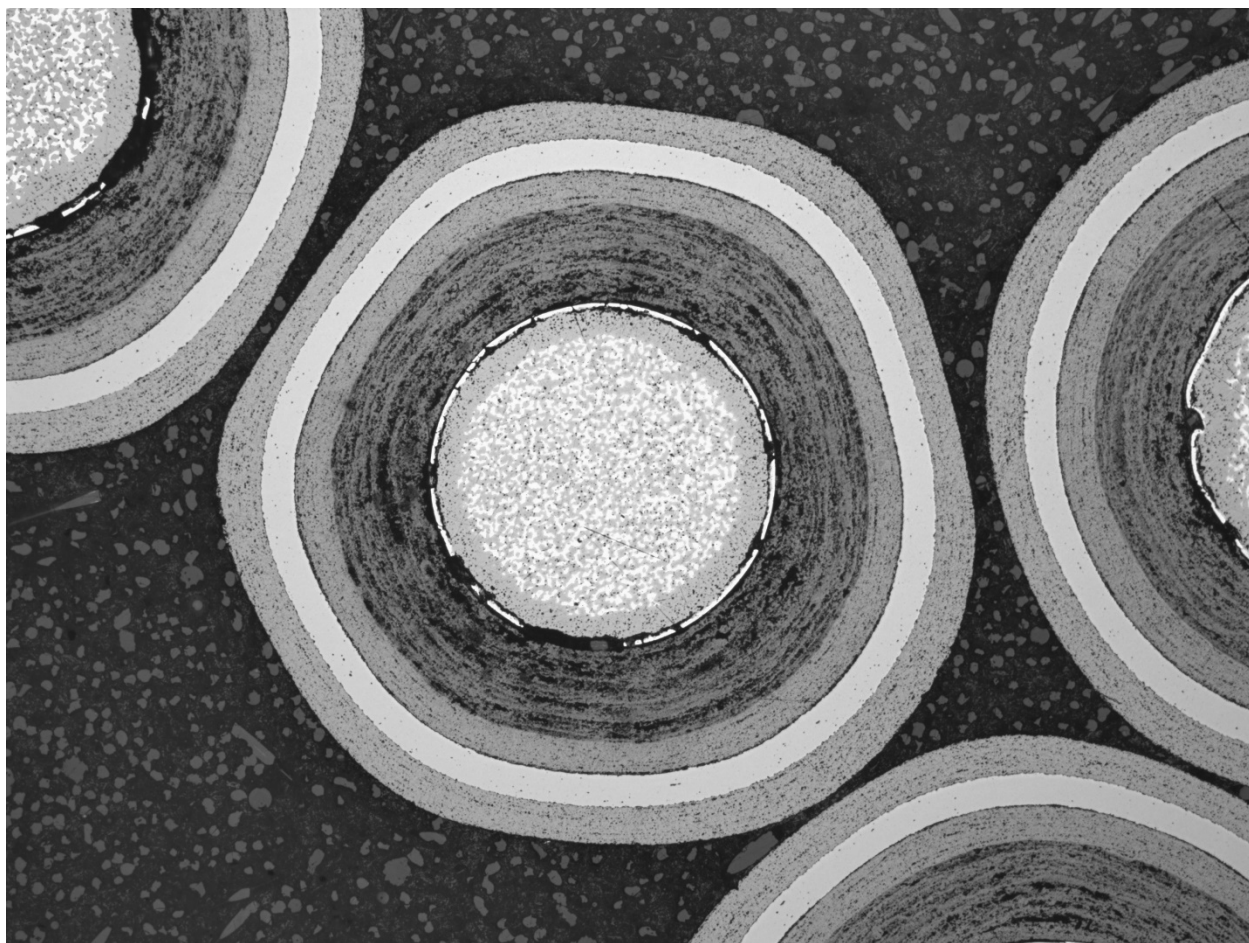


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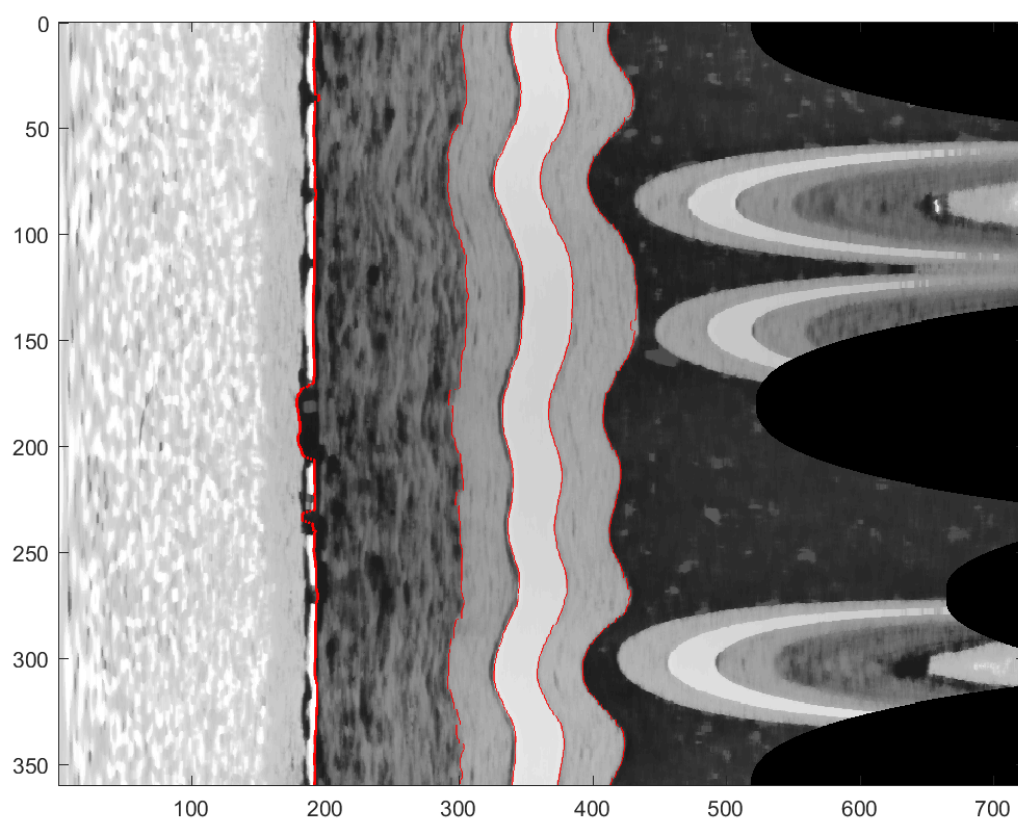
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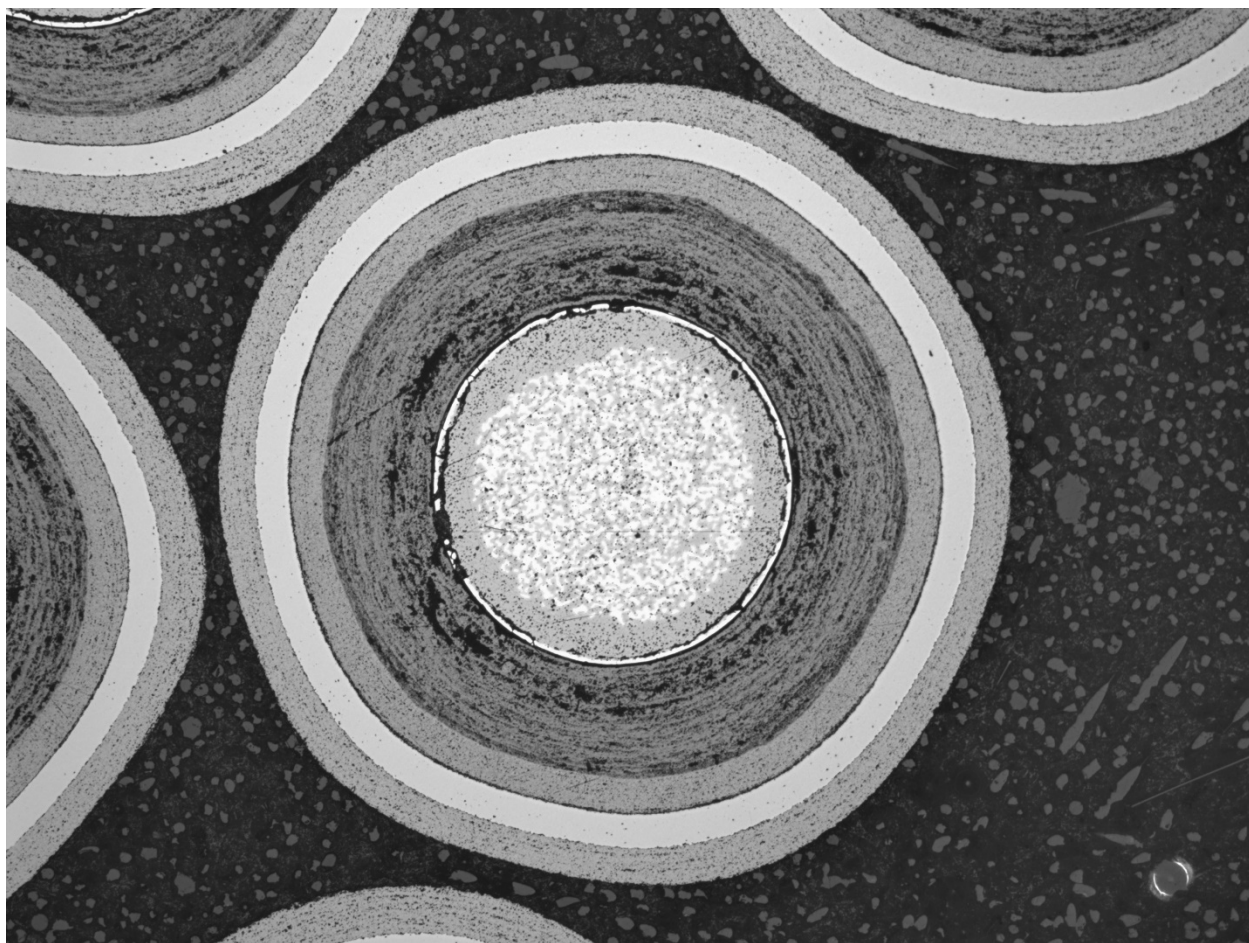


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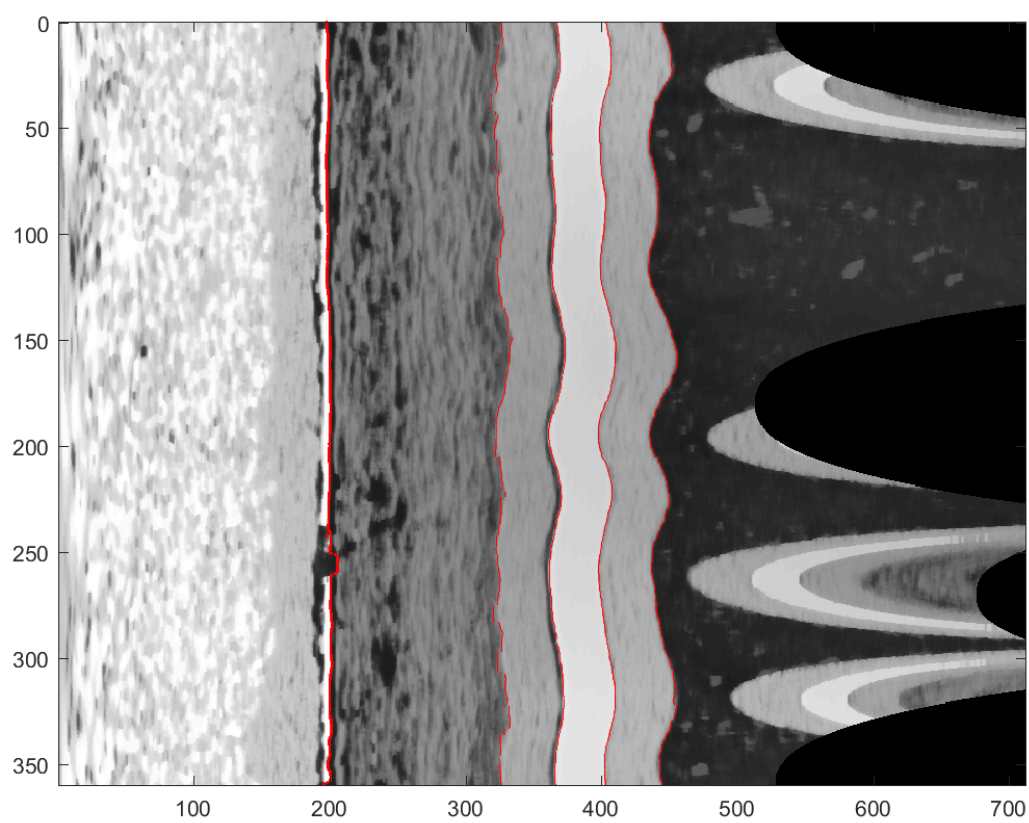




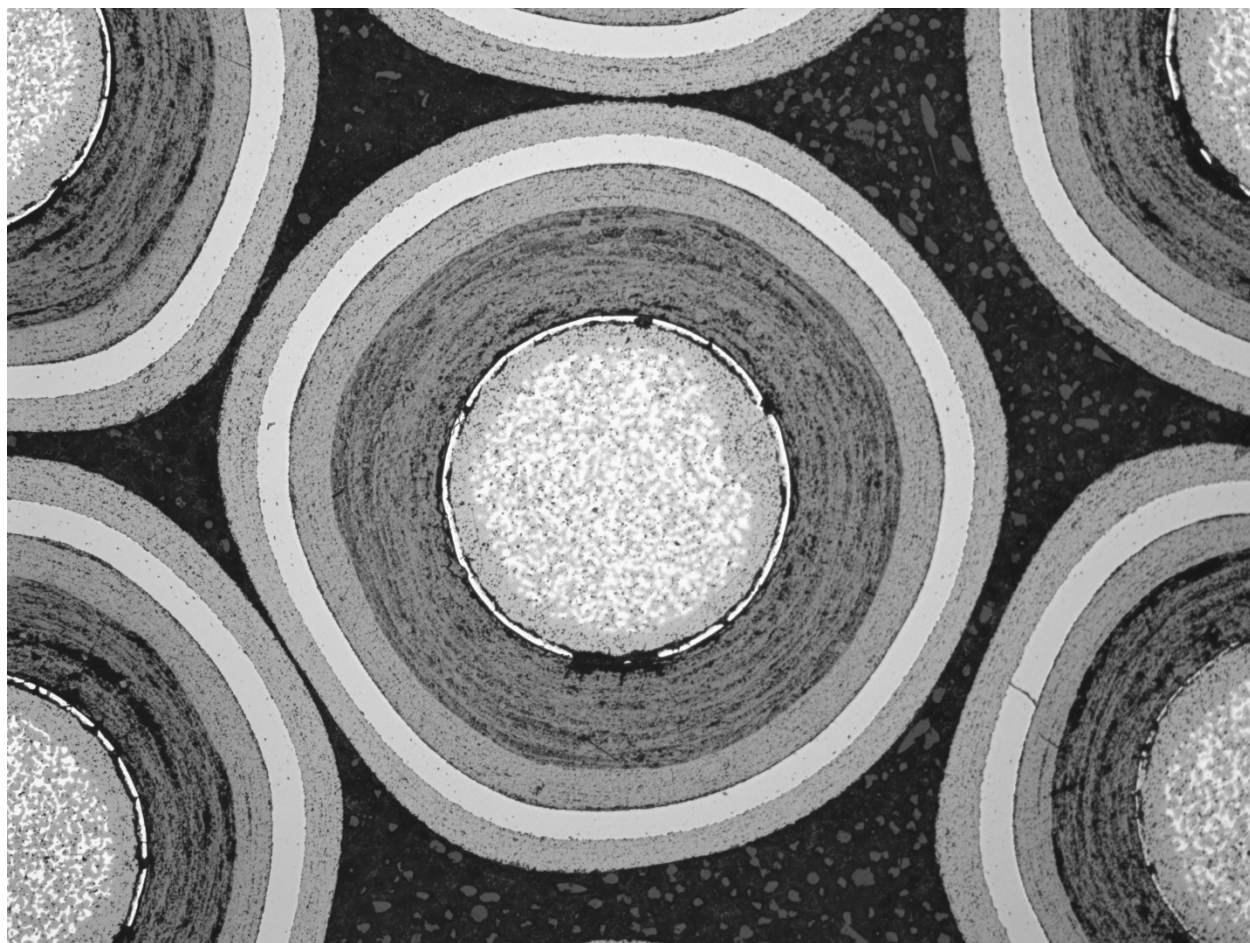
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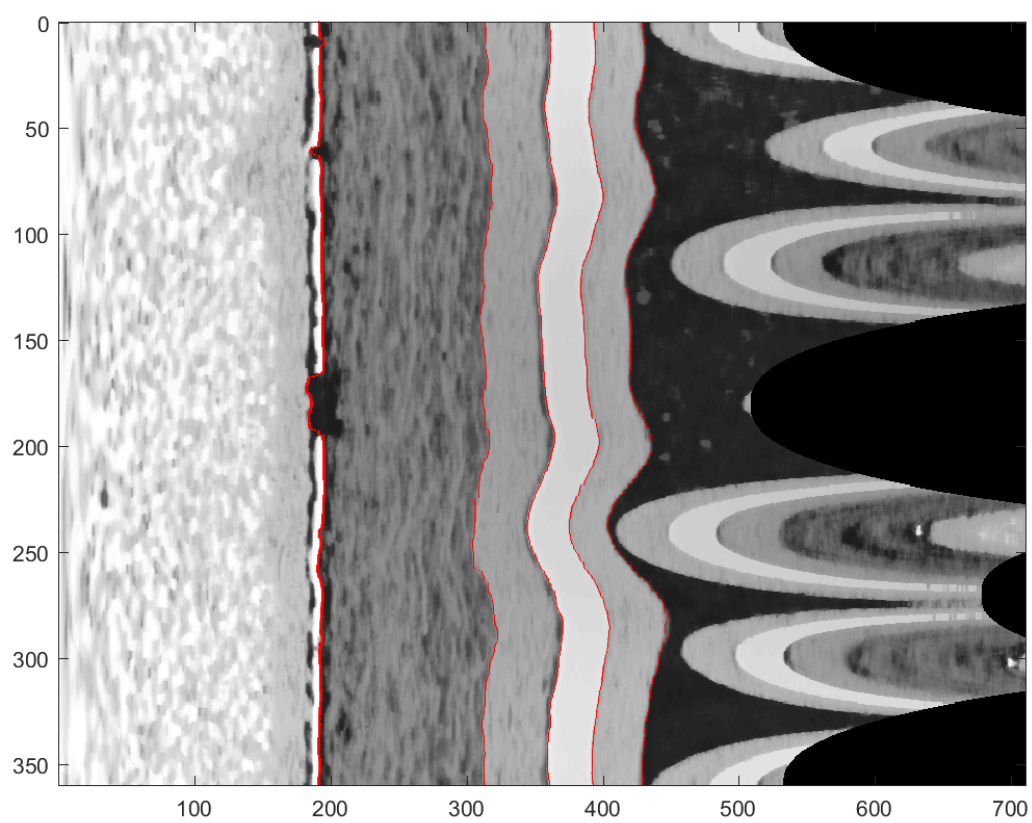
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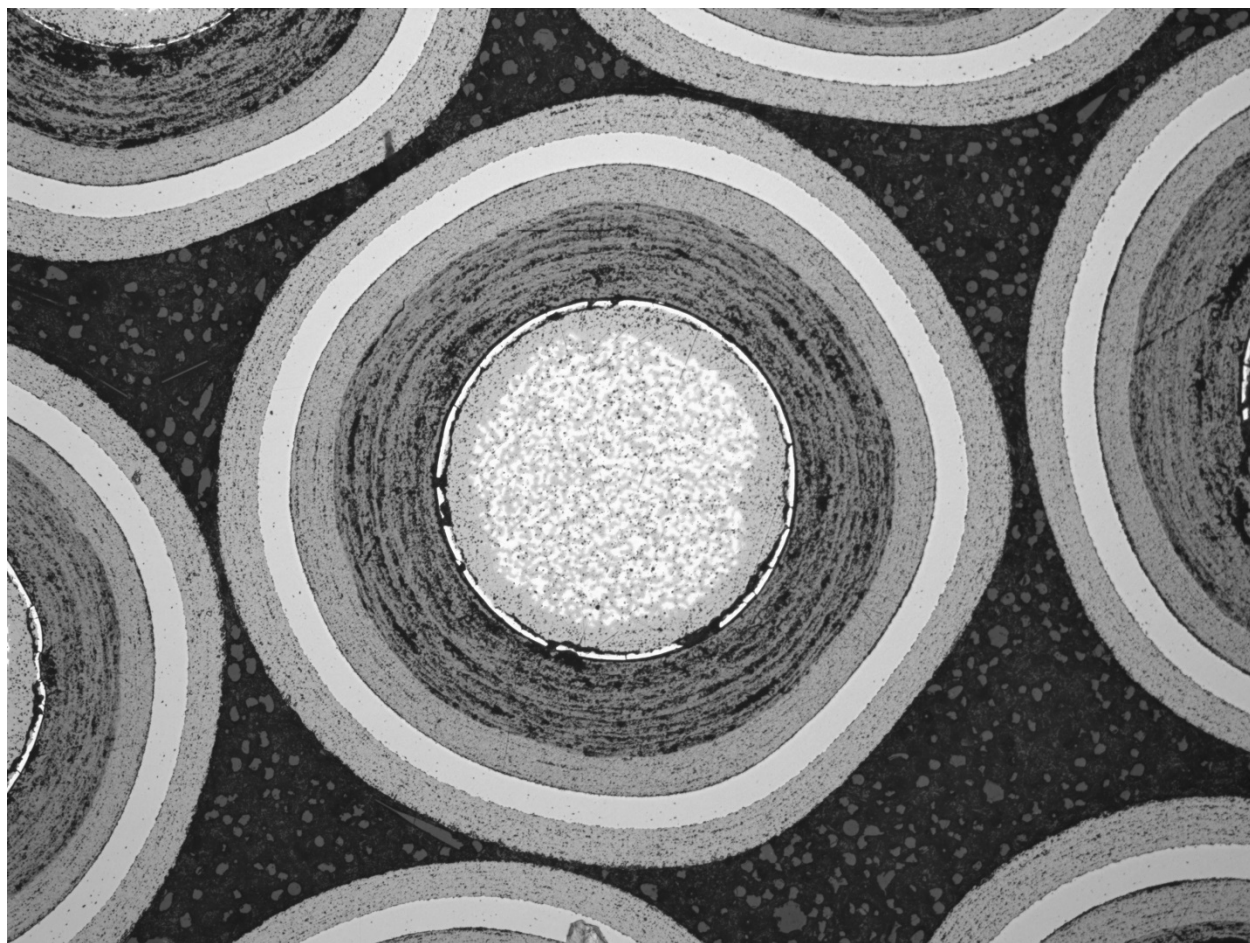
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P16082301N017

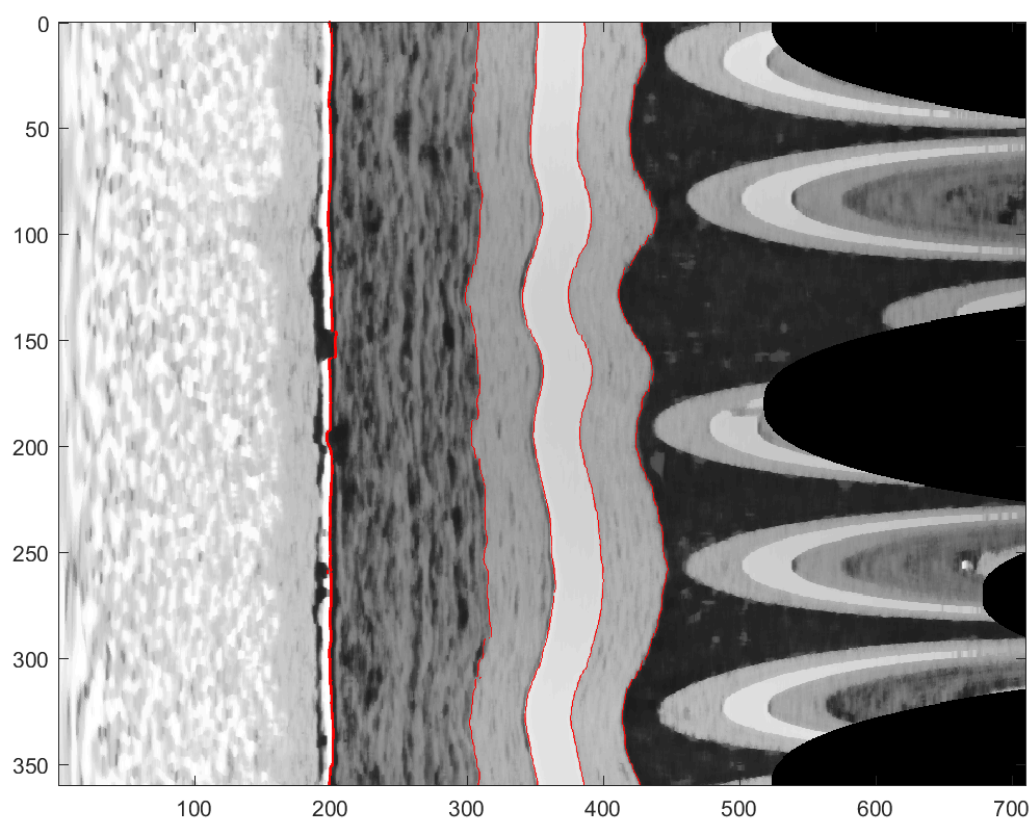


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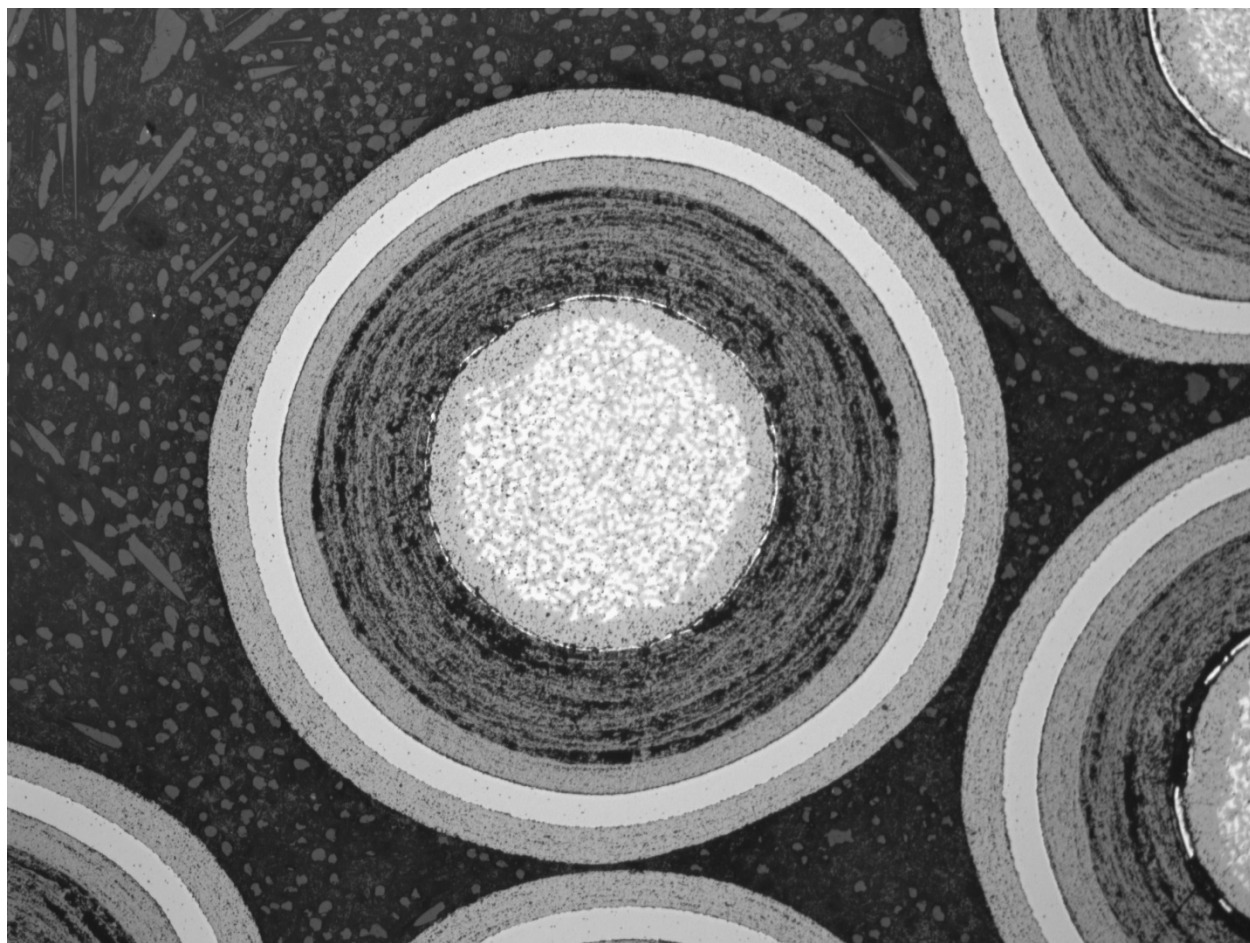
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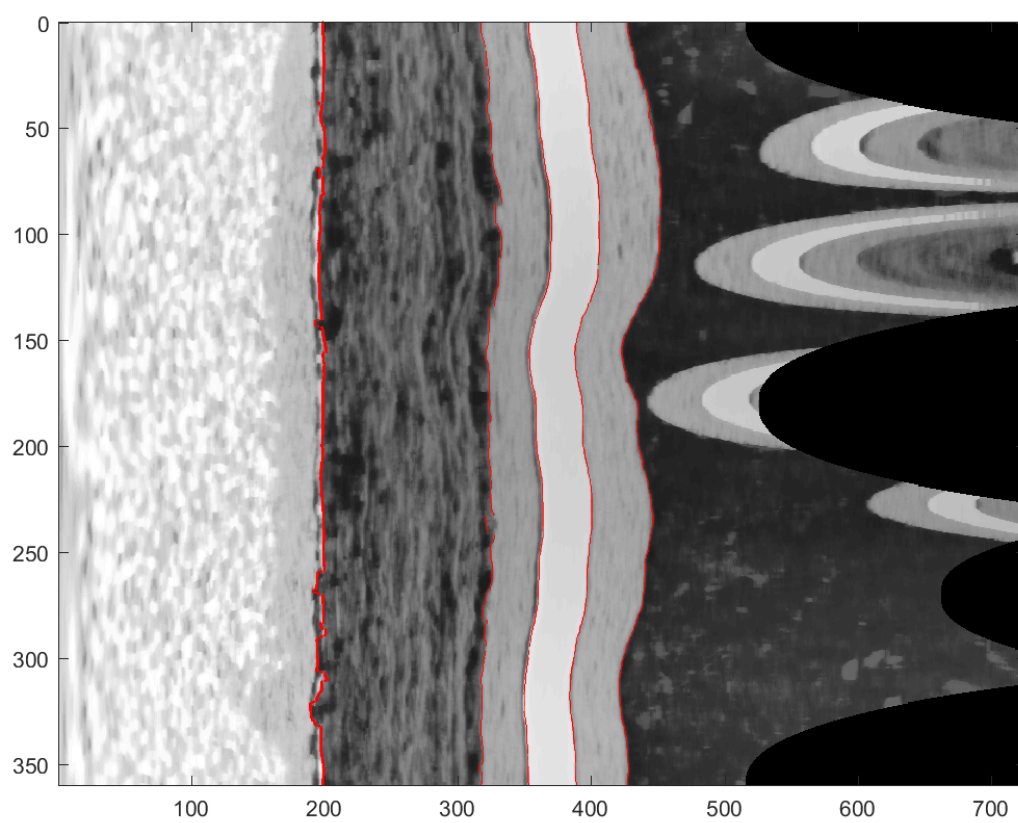


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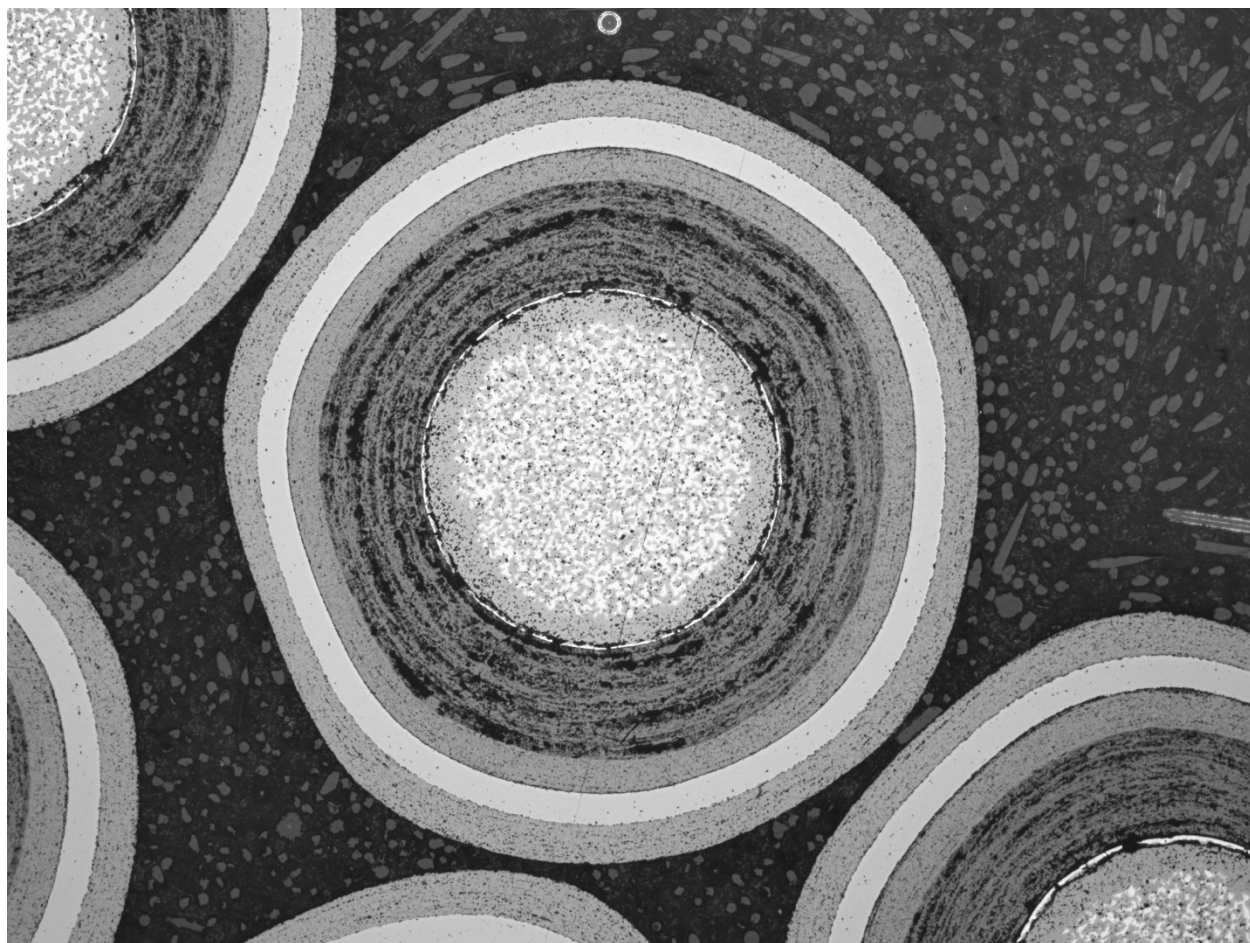




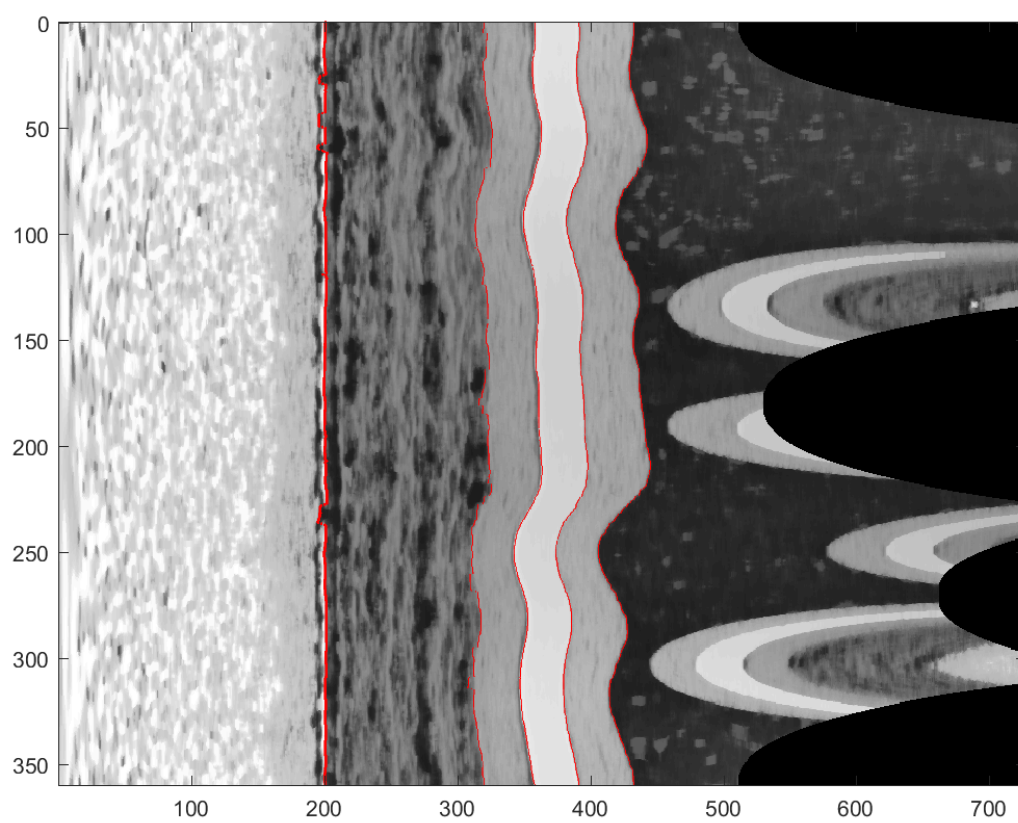
P16082301N019



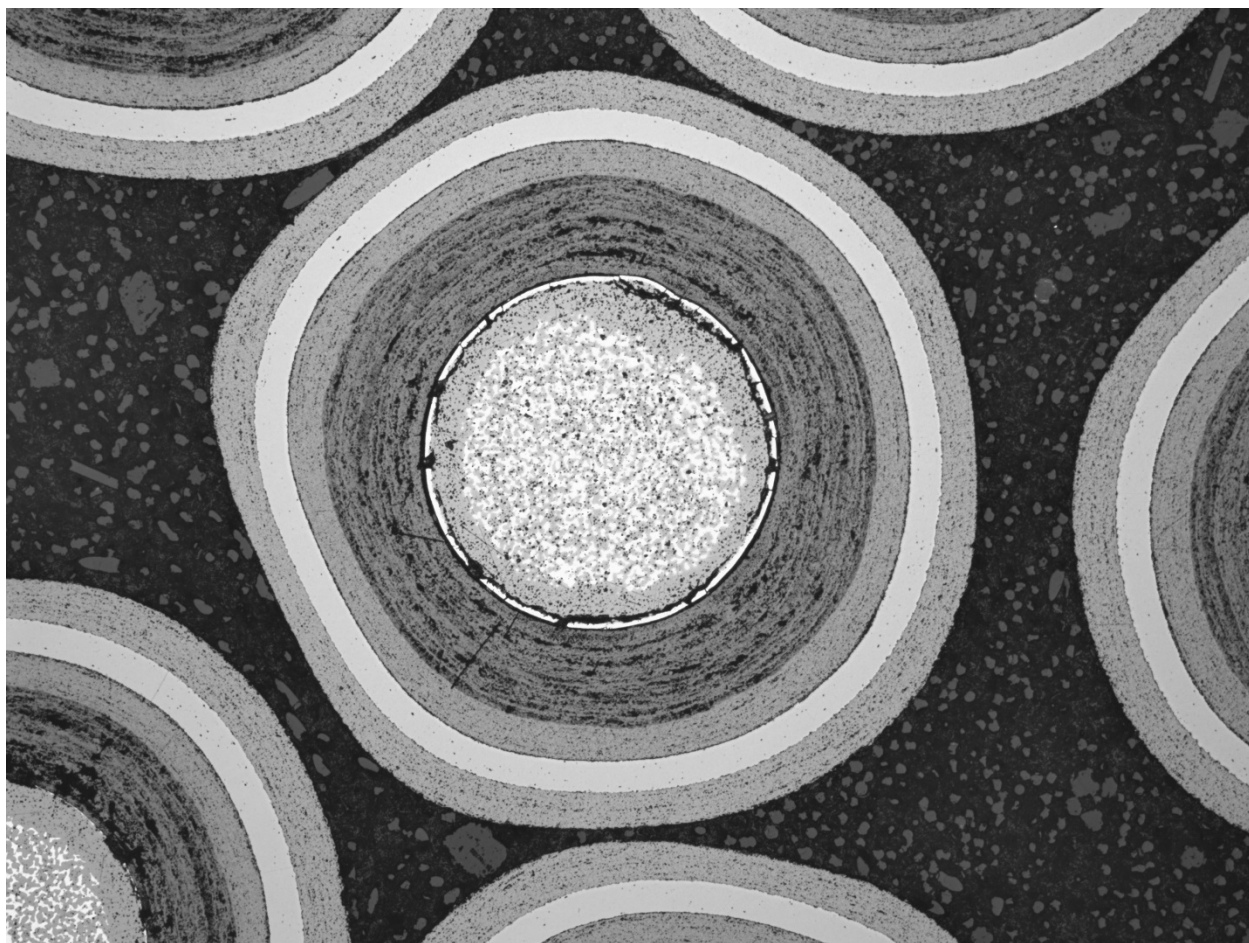
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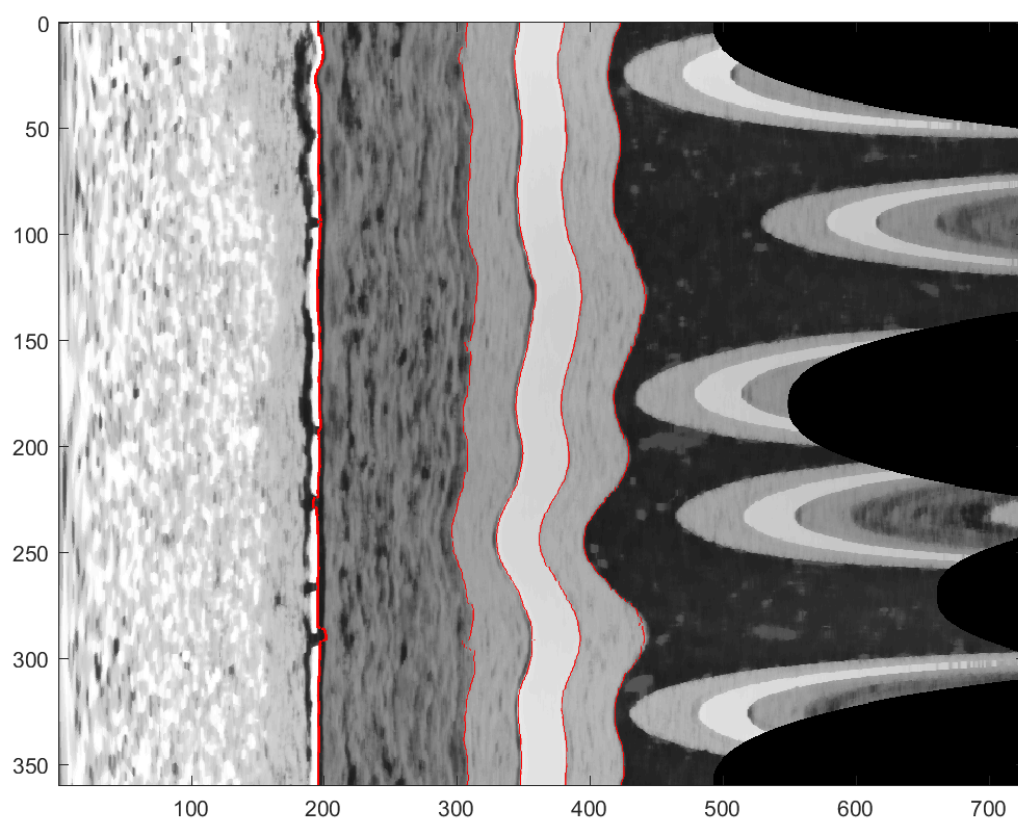
P16082301N020



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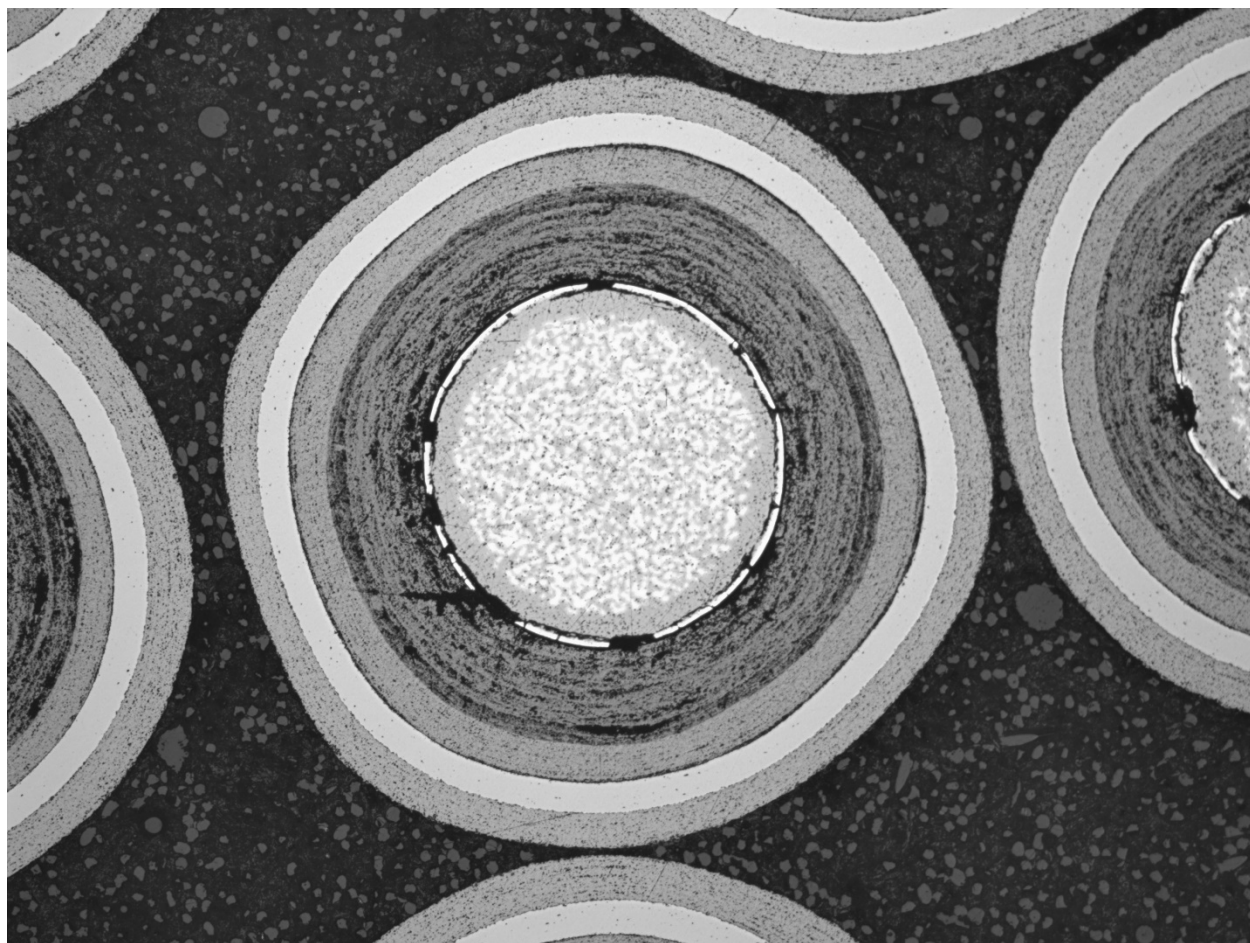


P16082301N022



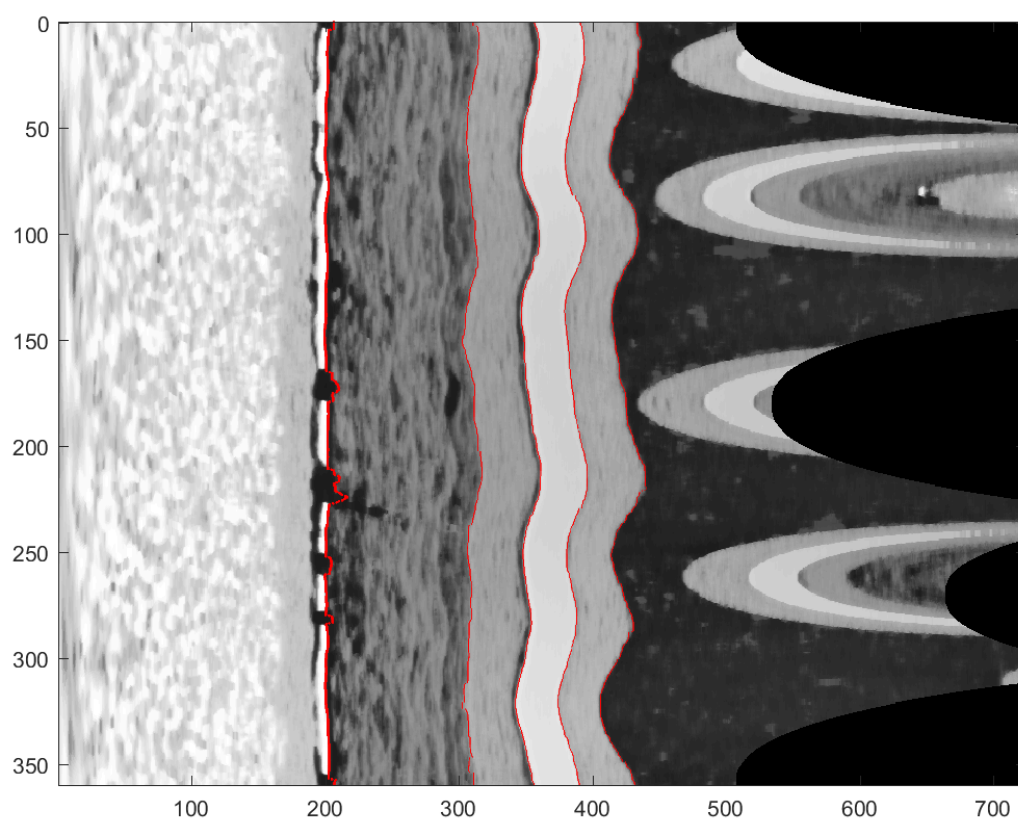
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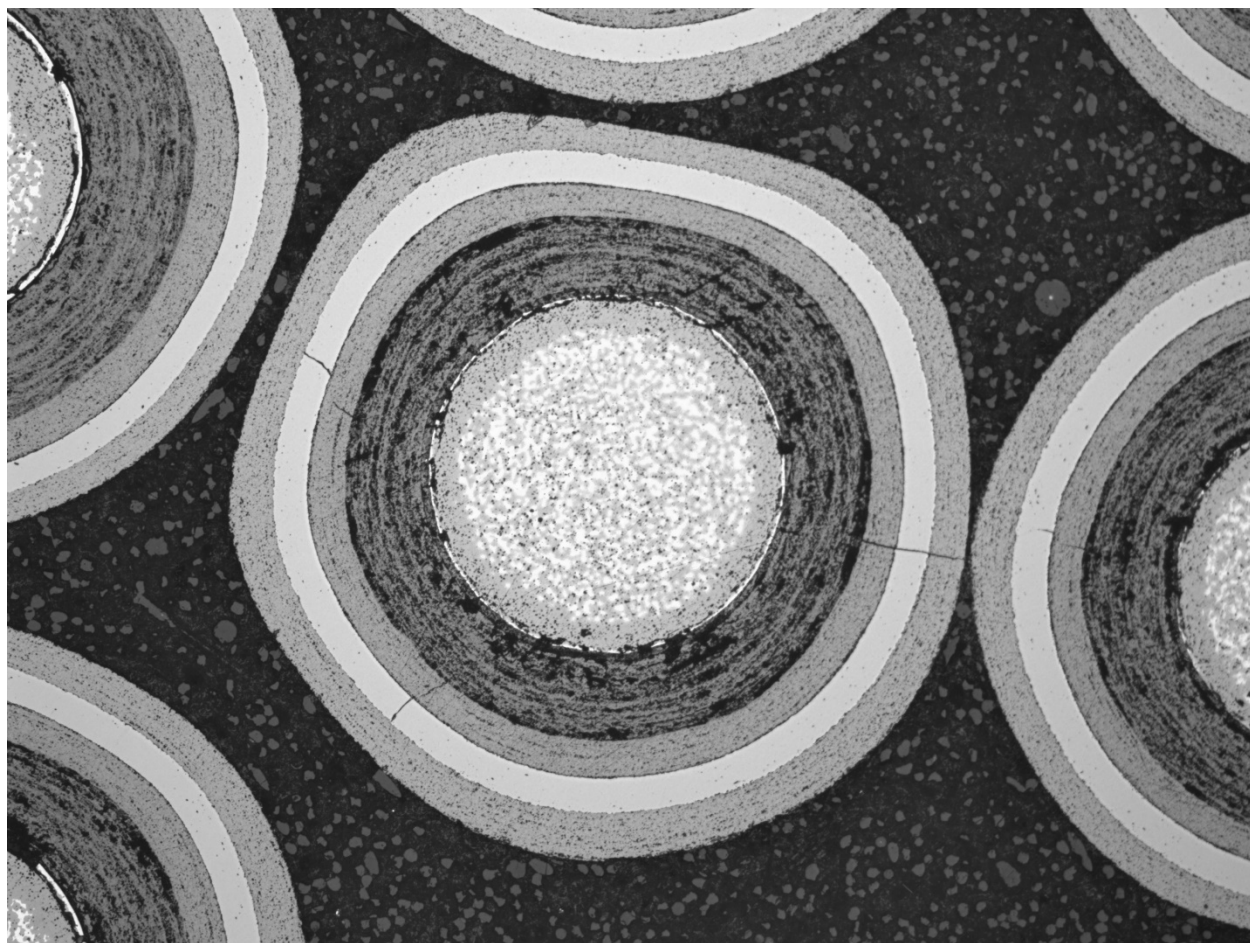


P16082301N023

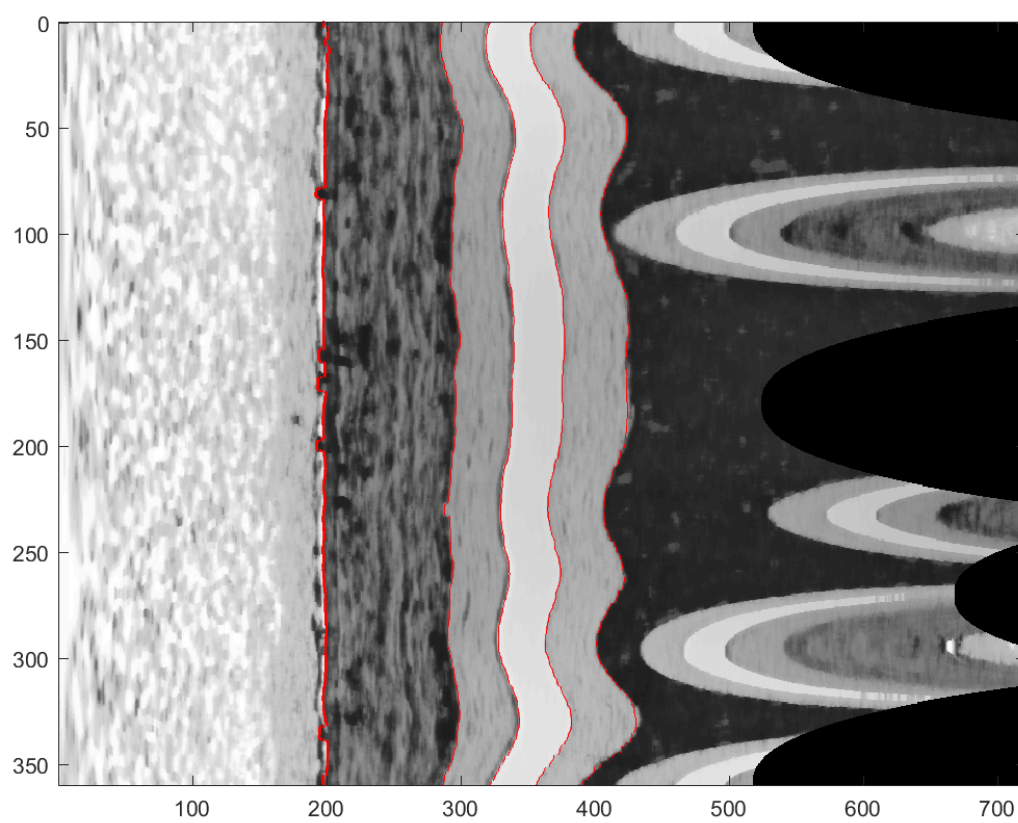




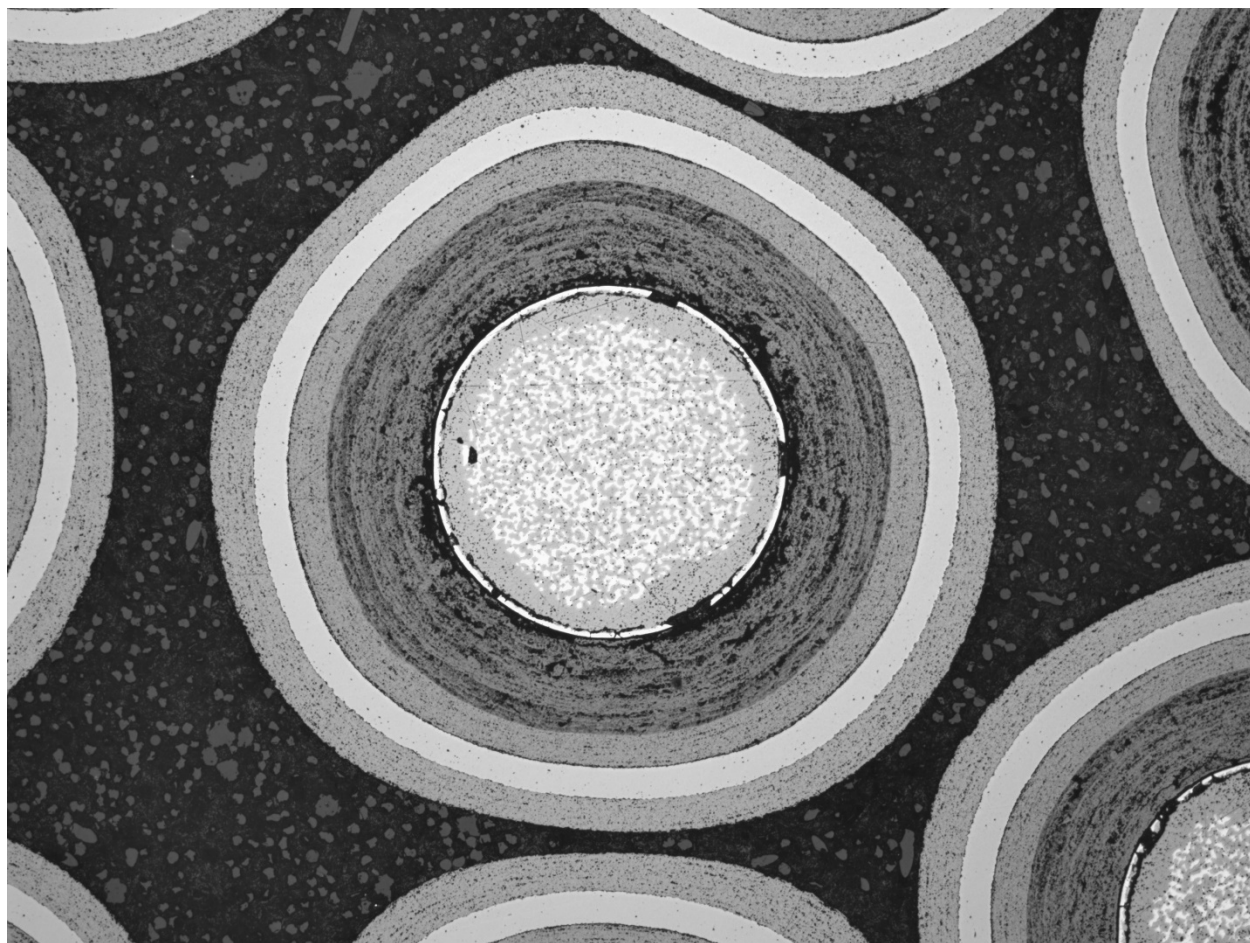
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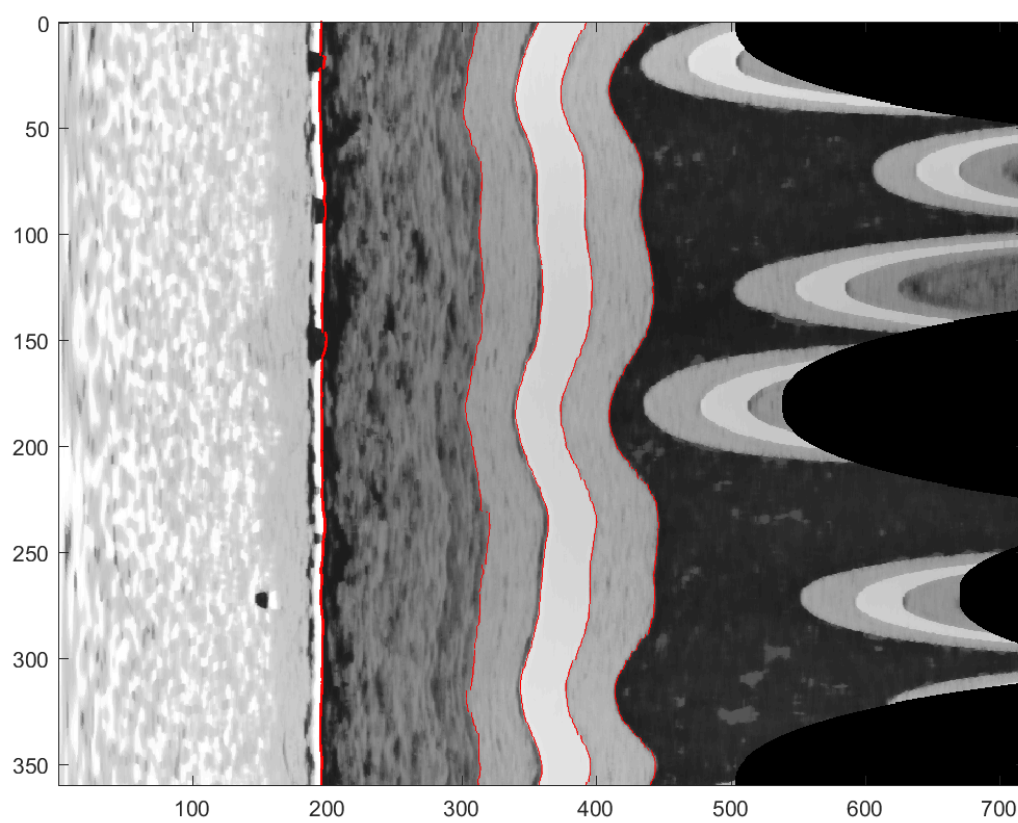
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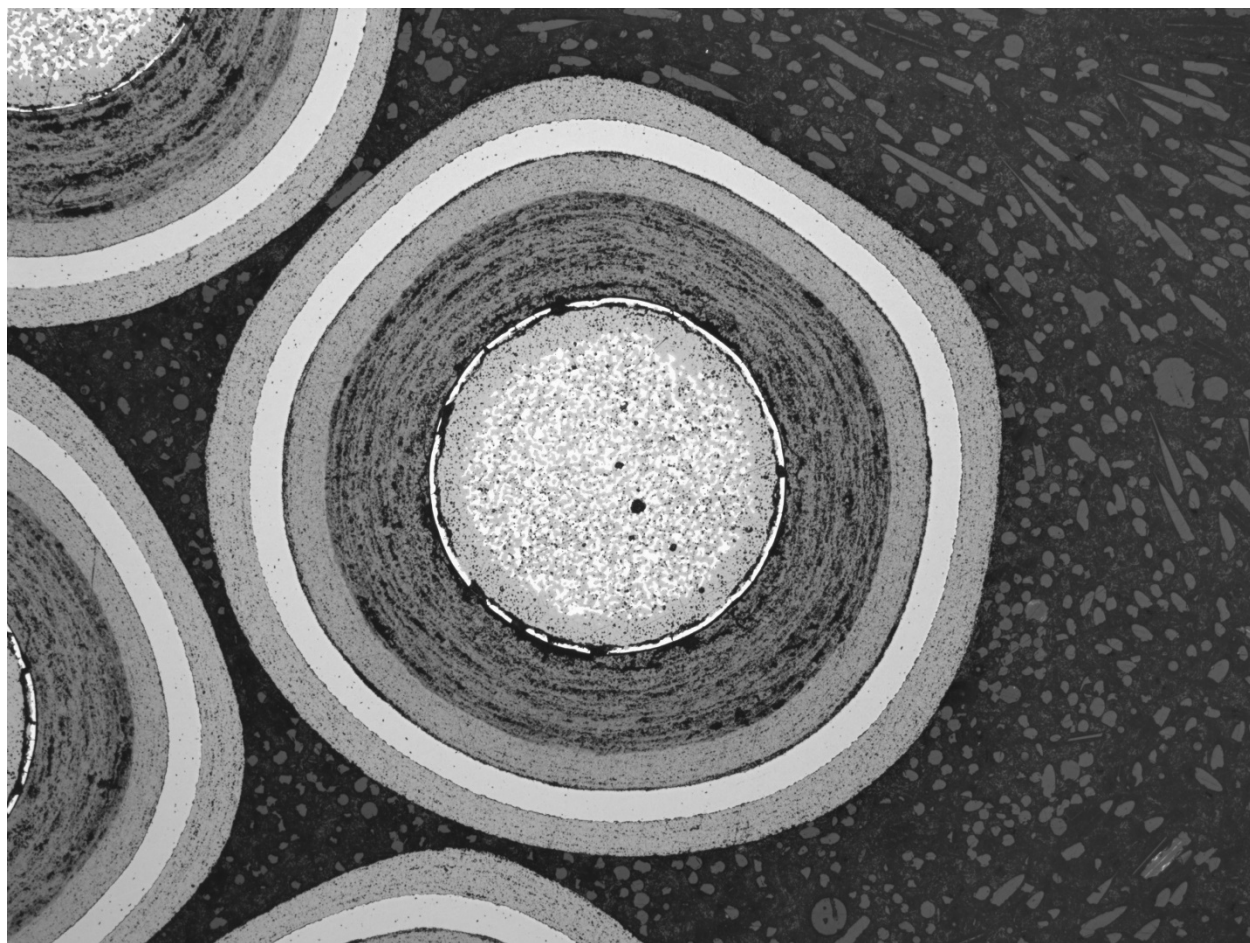
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P16082301N026

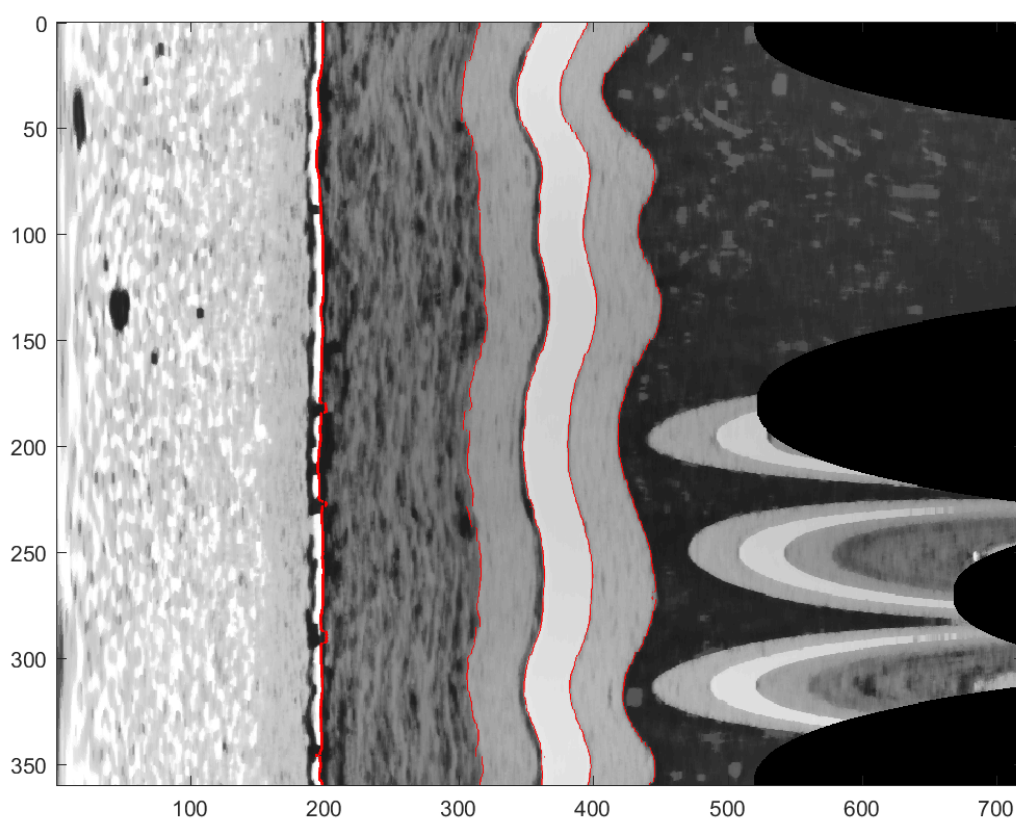


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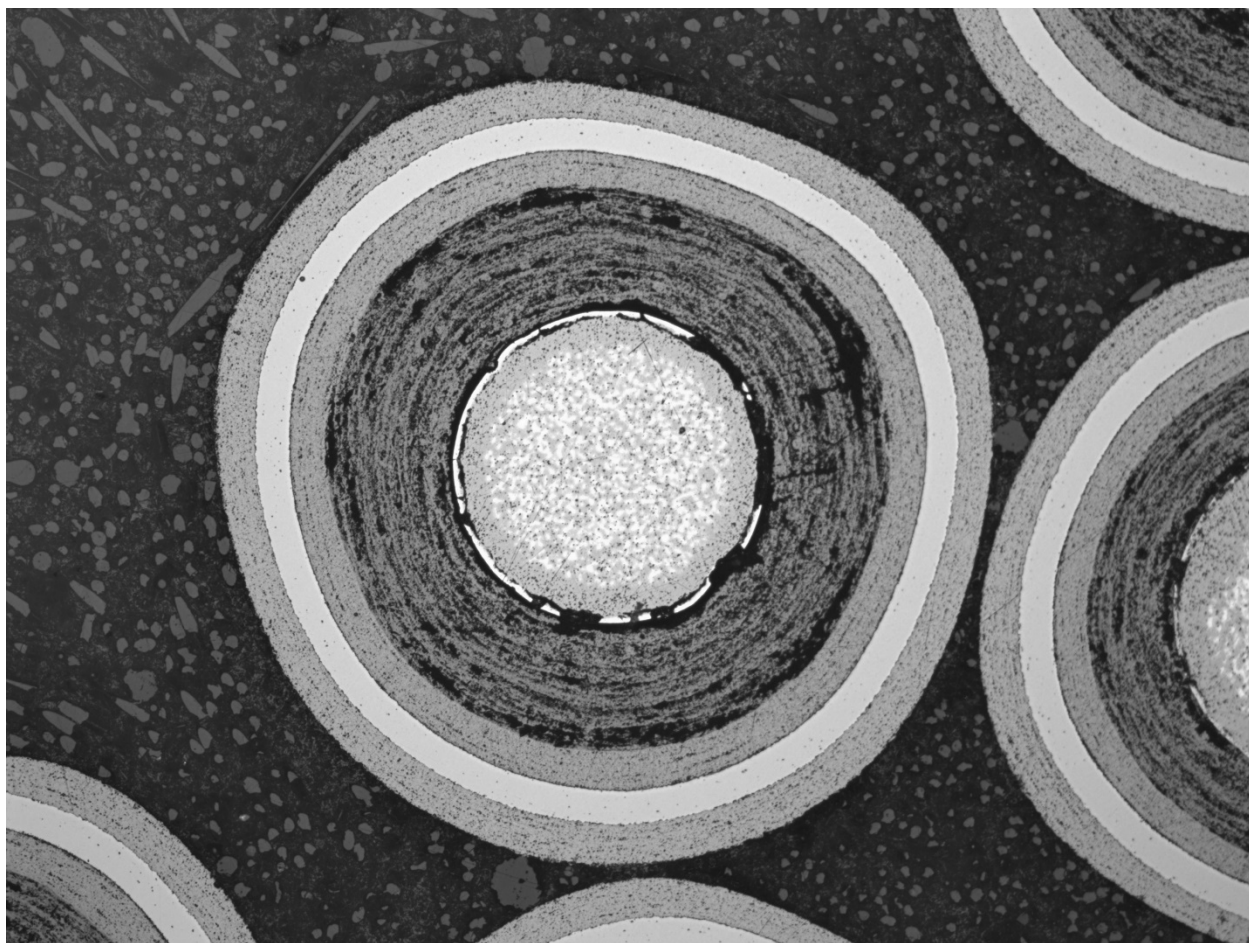
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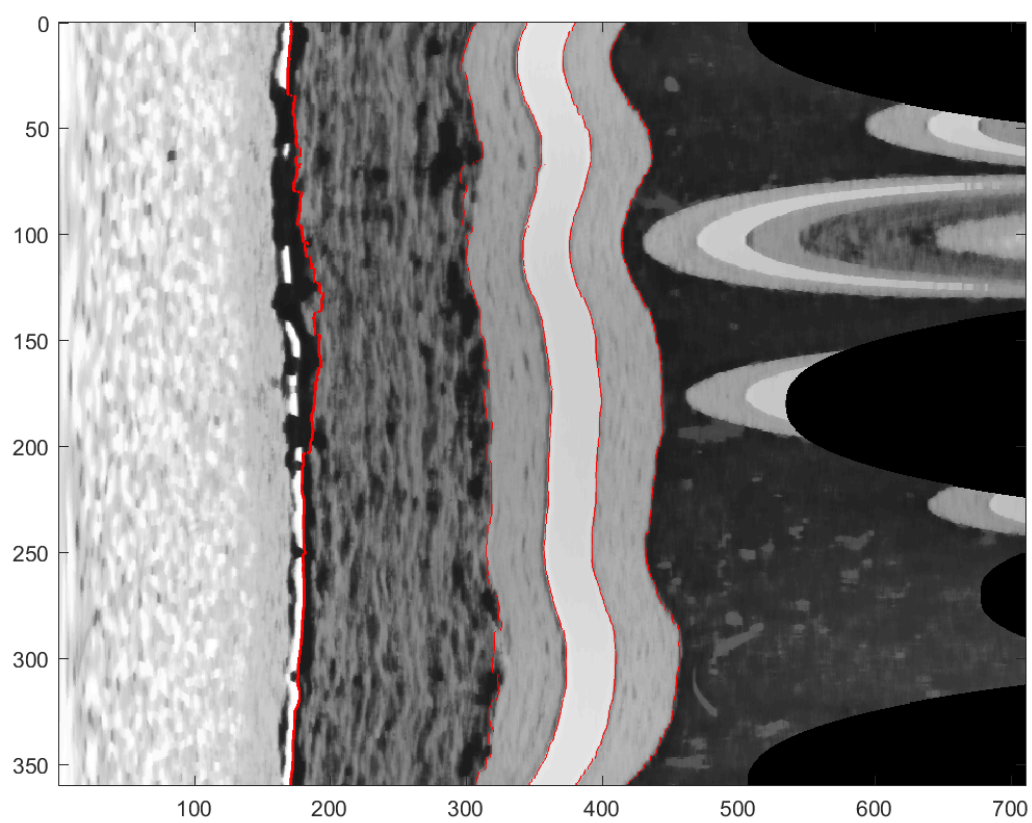


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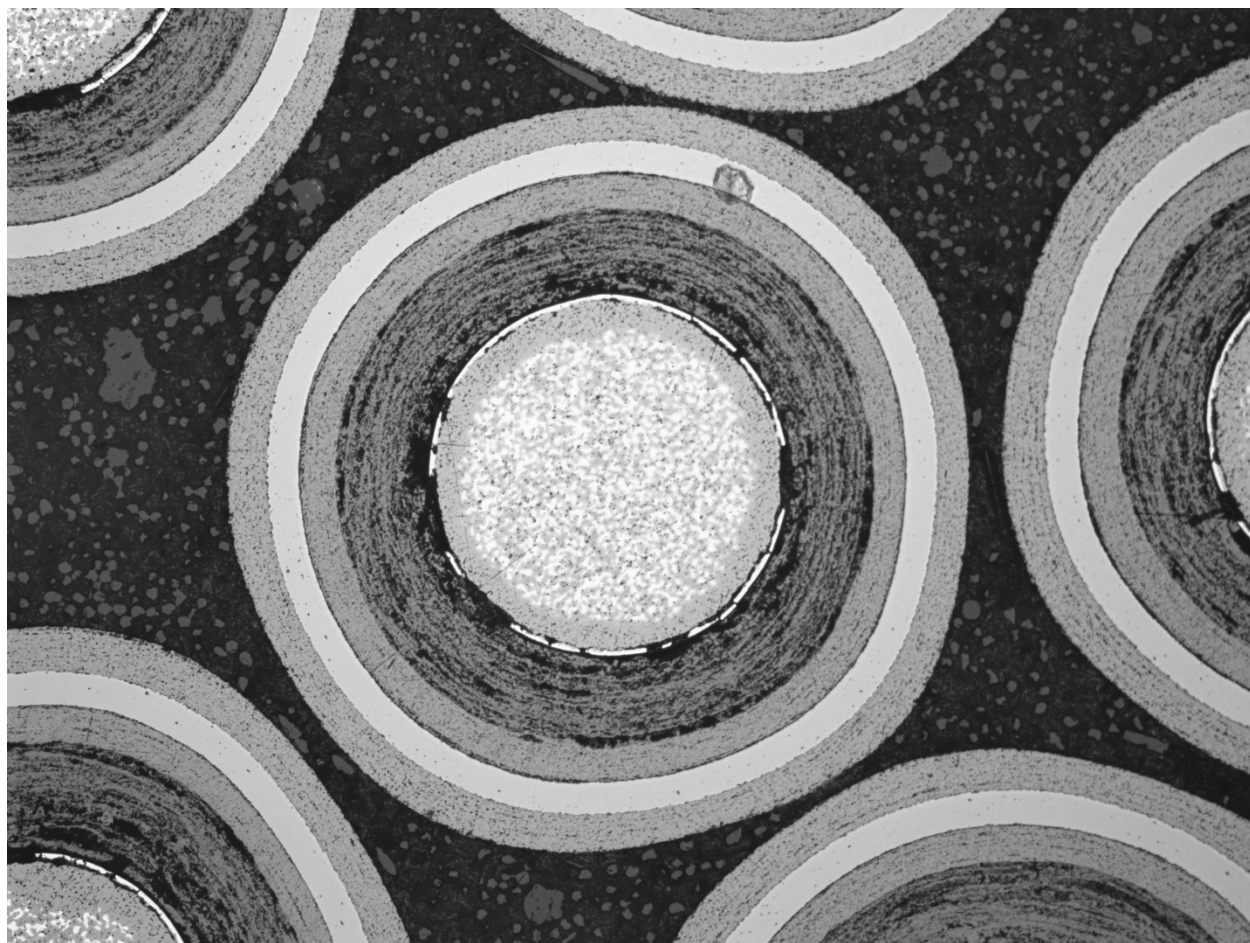




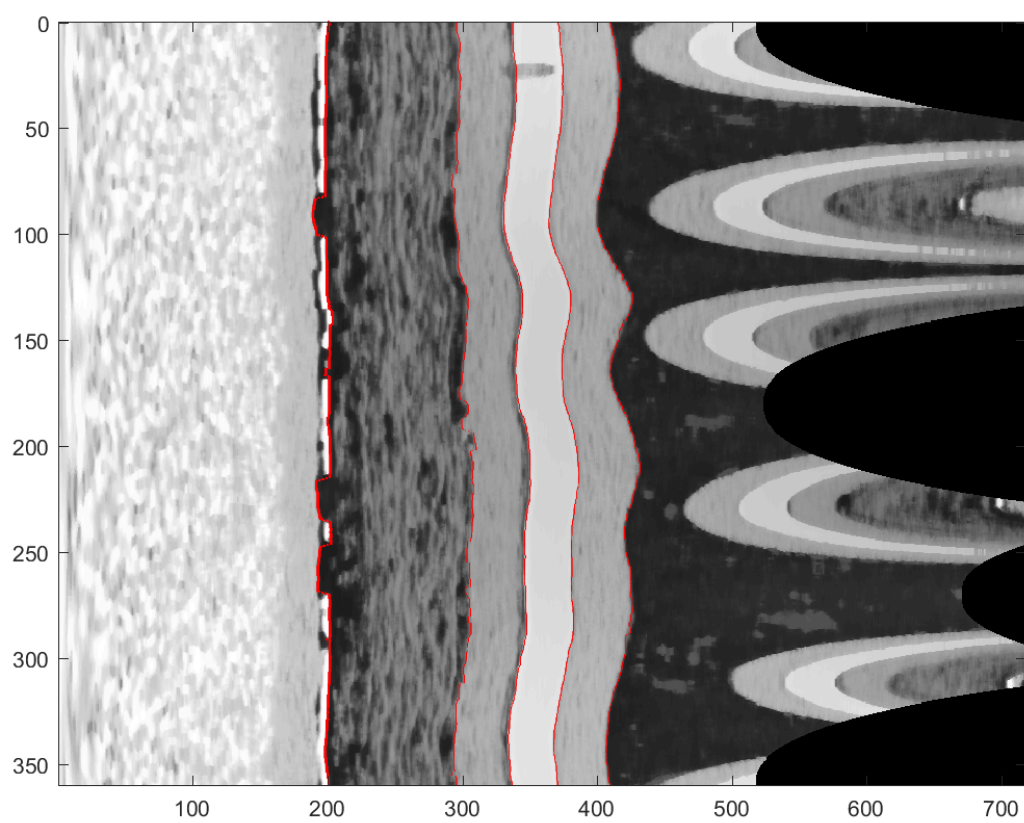
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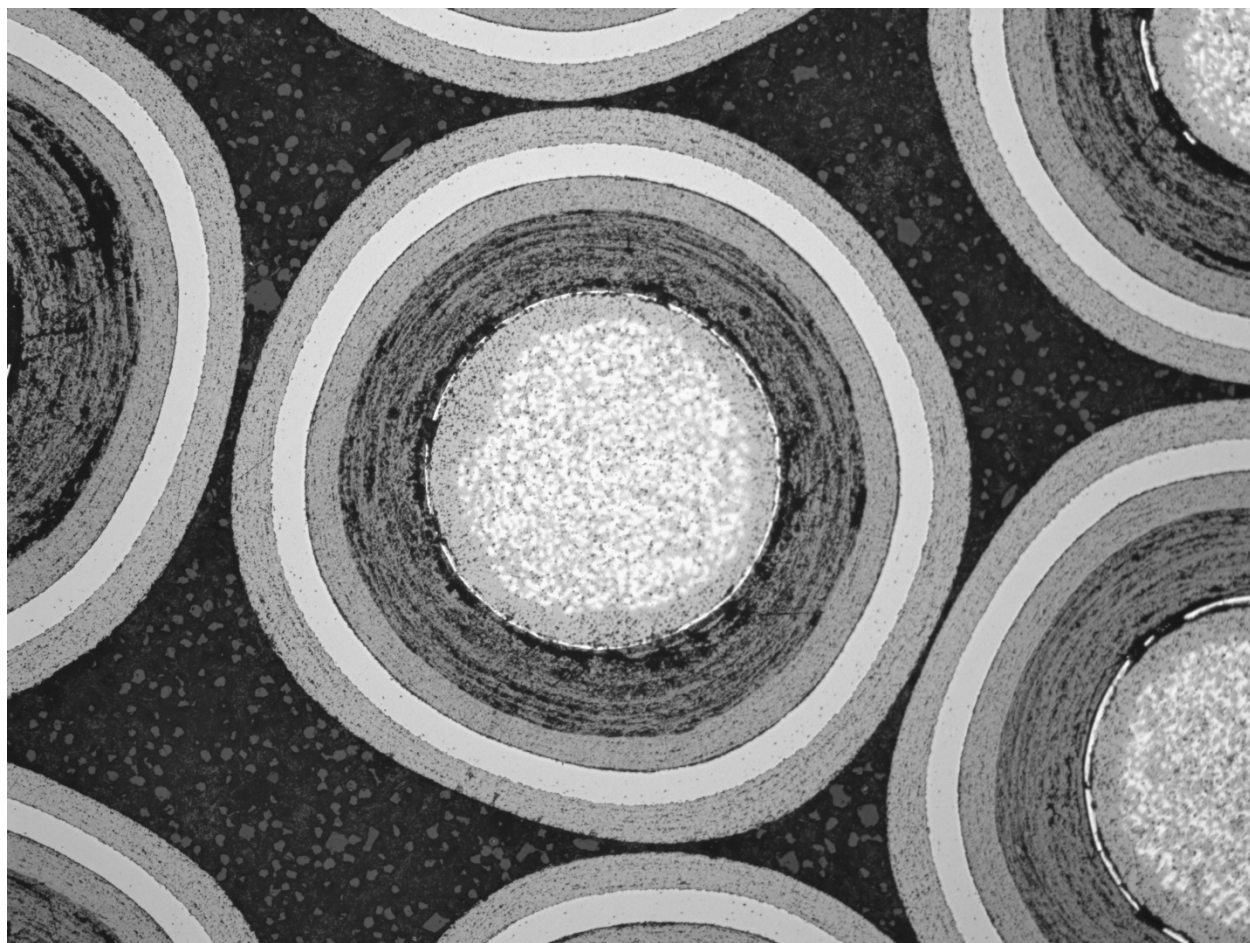
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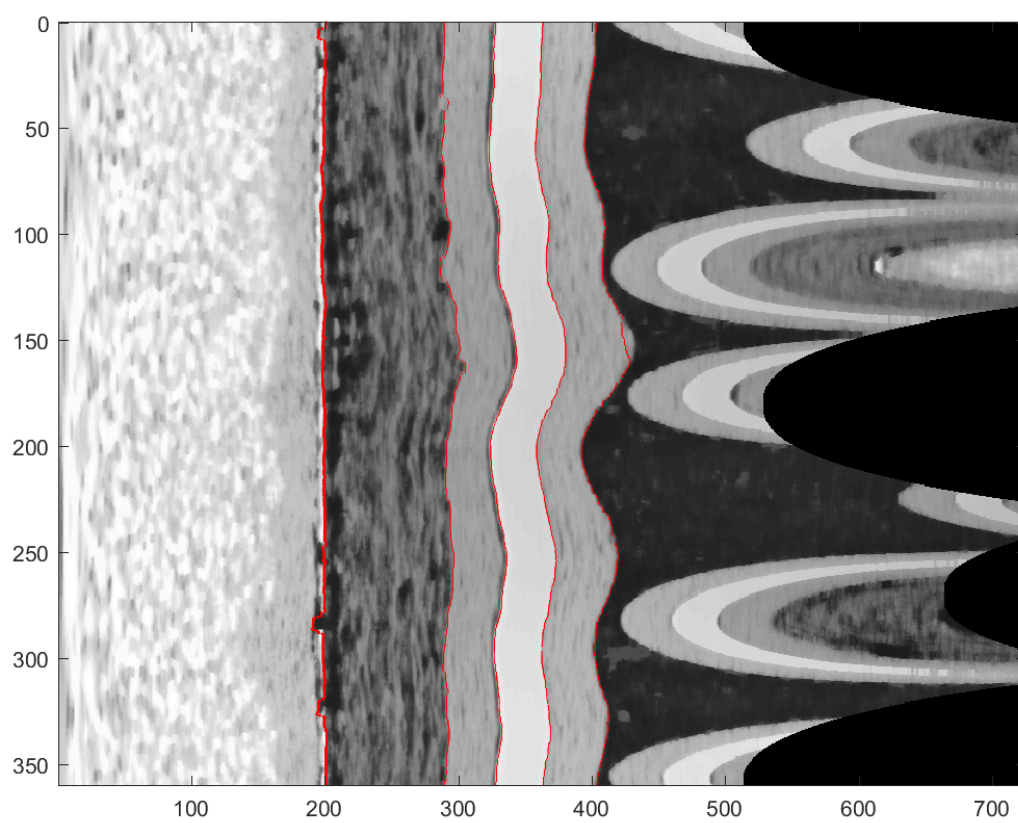
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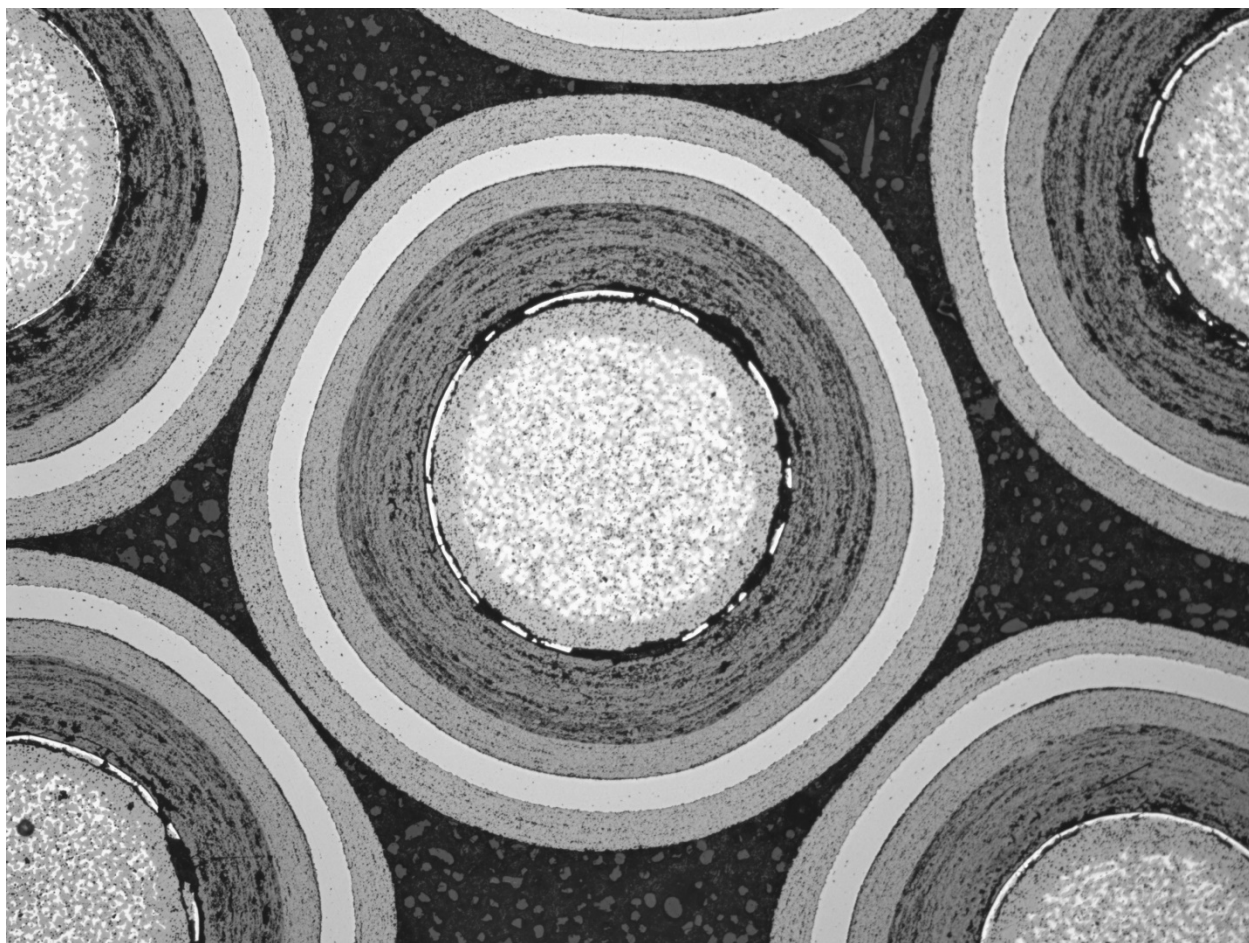


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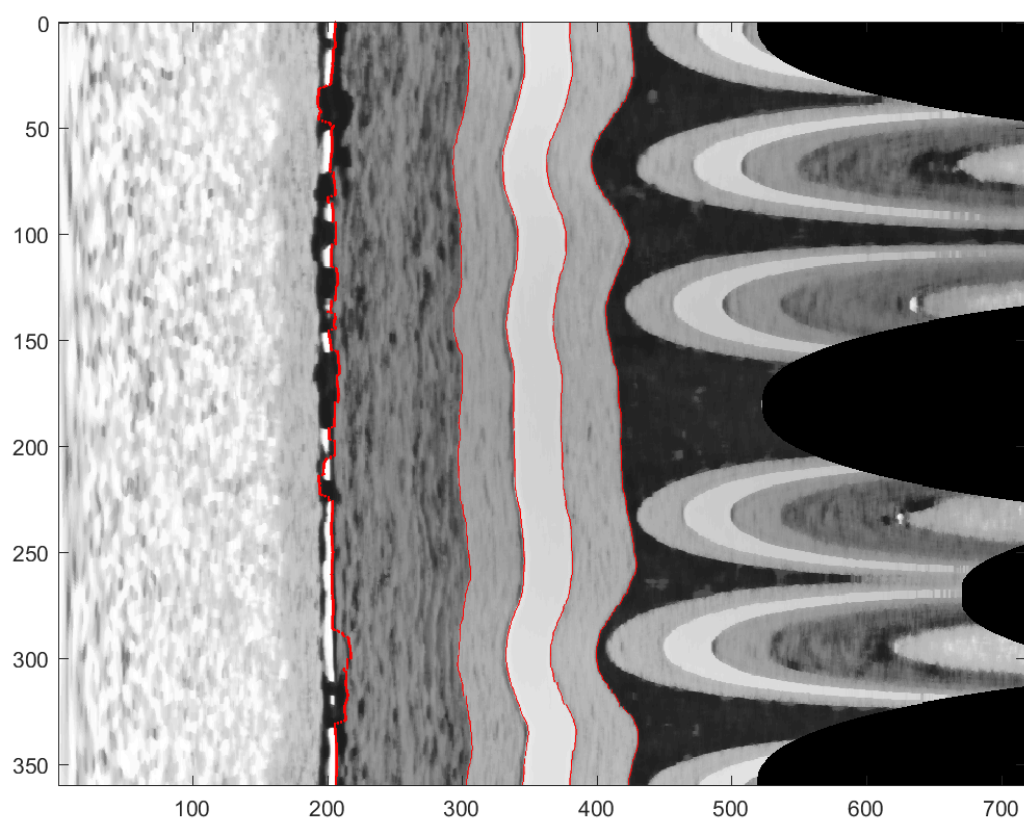
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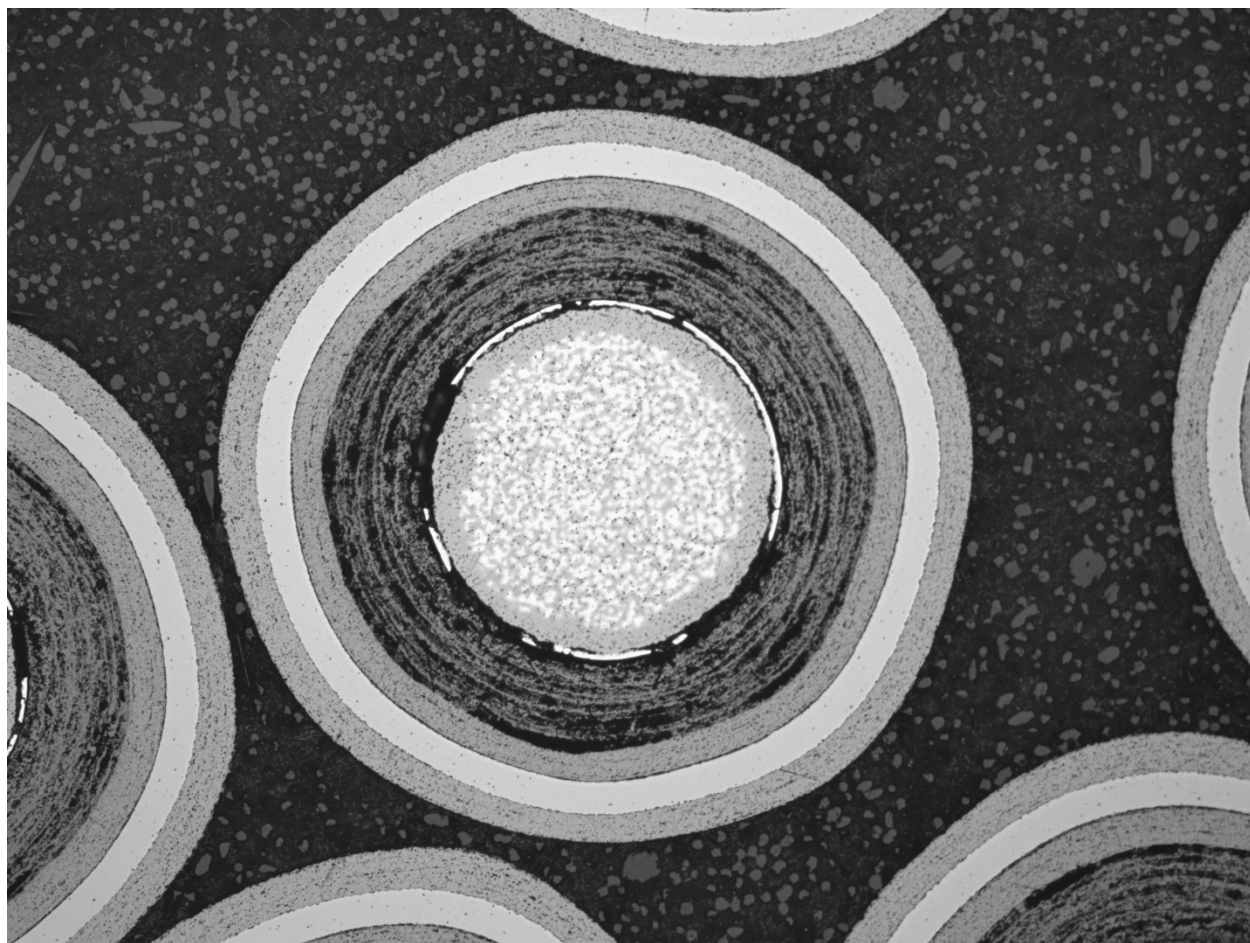


P16082301N038

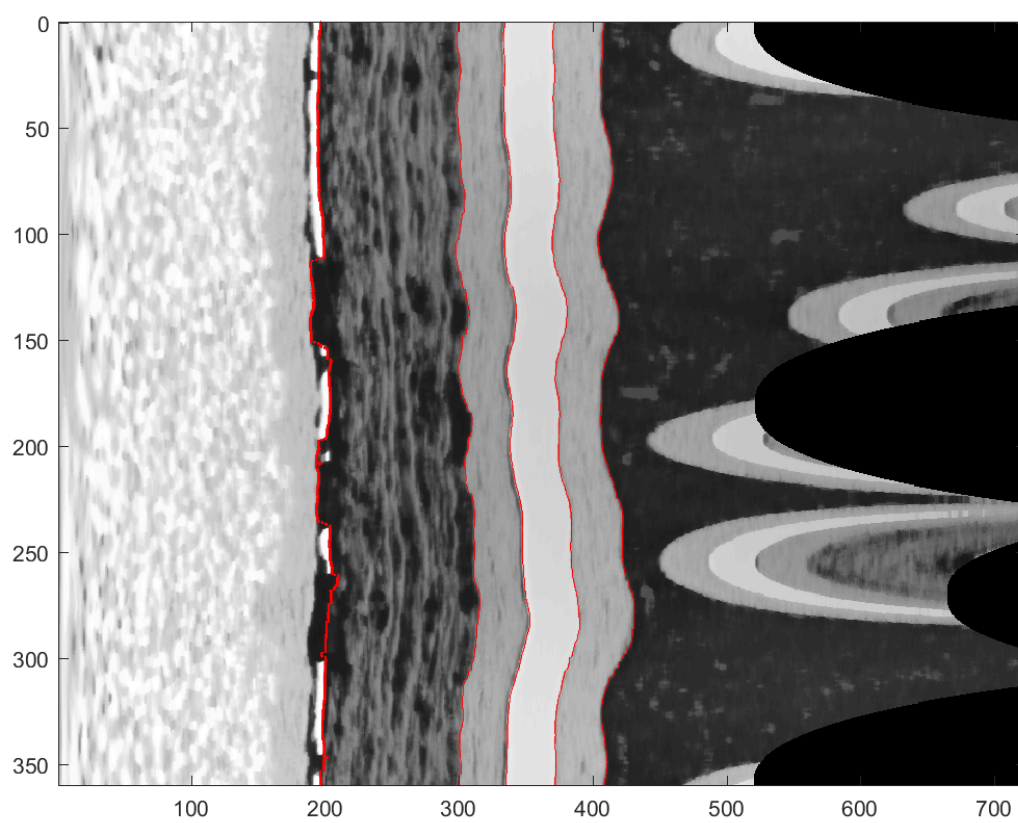




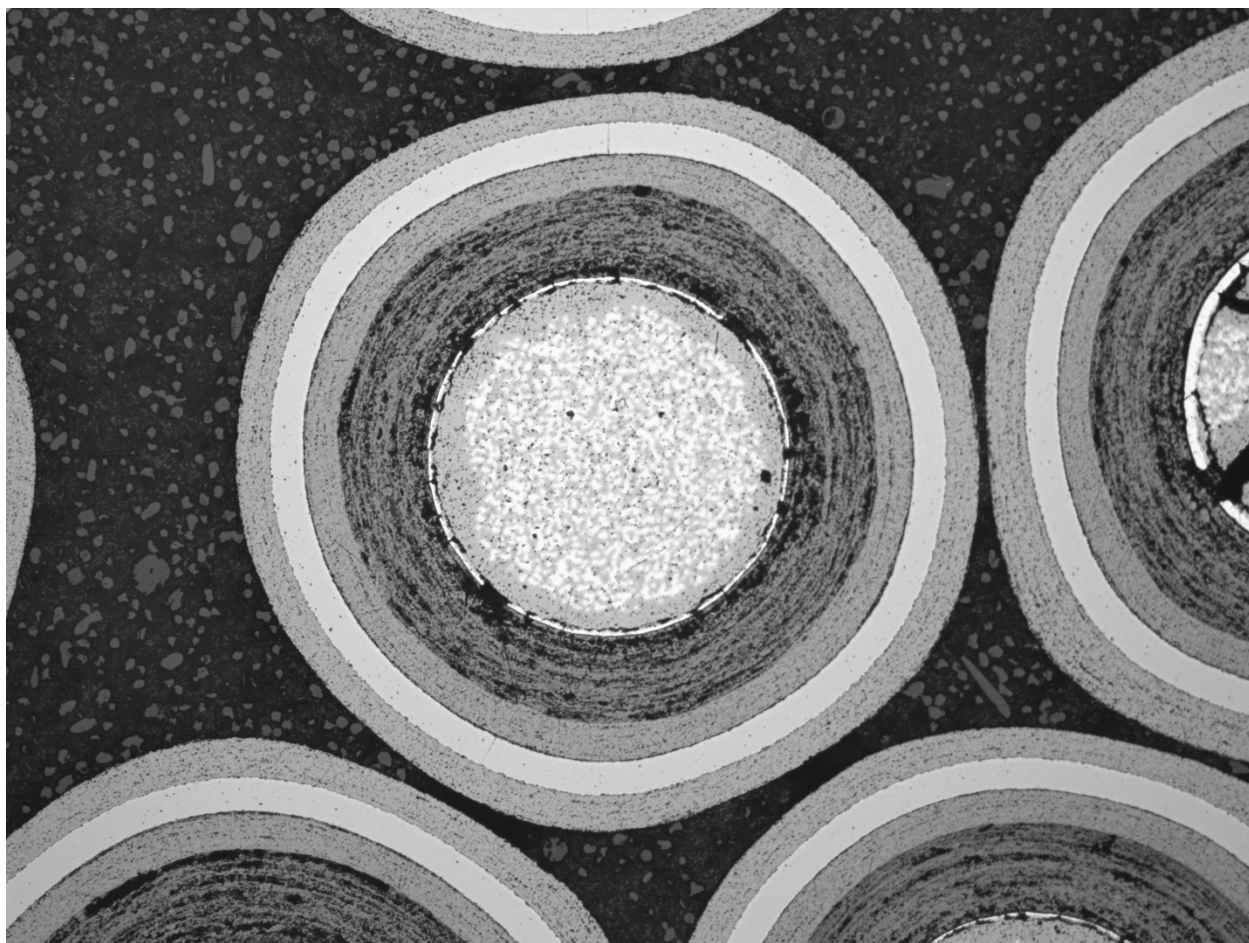
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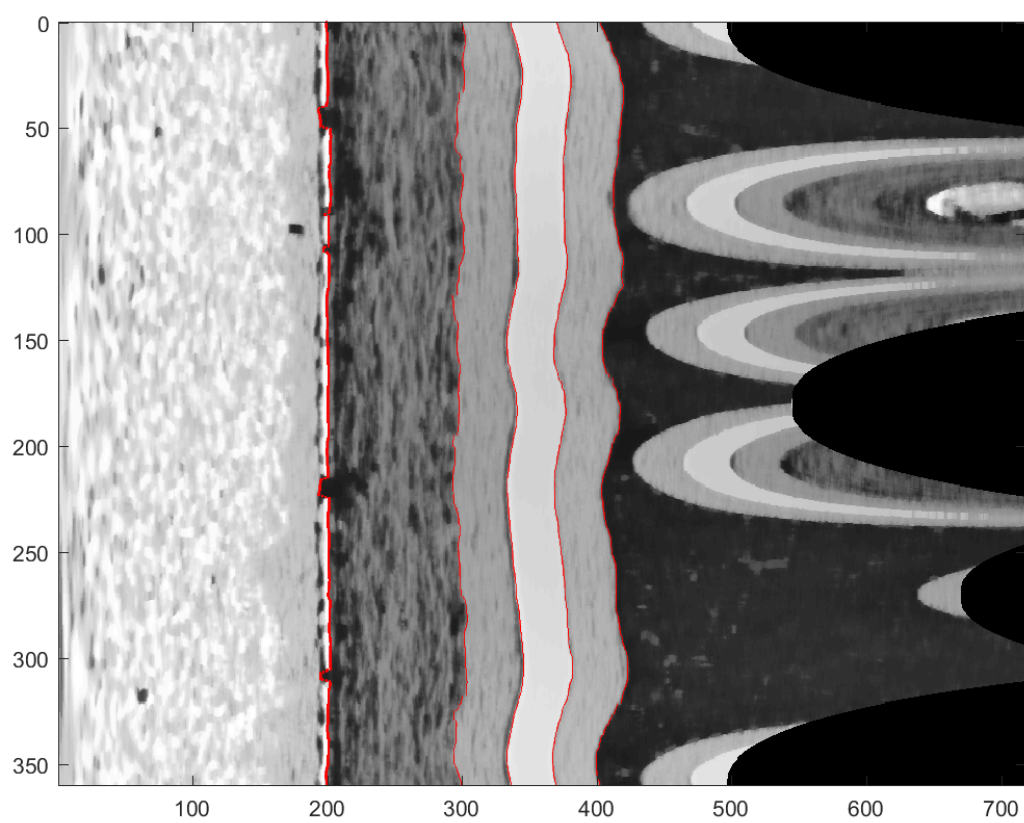
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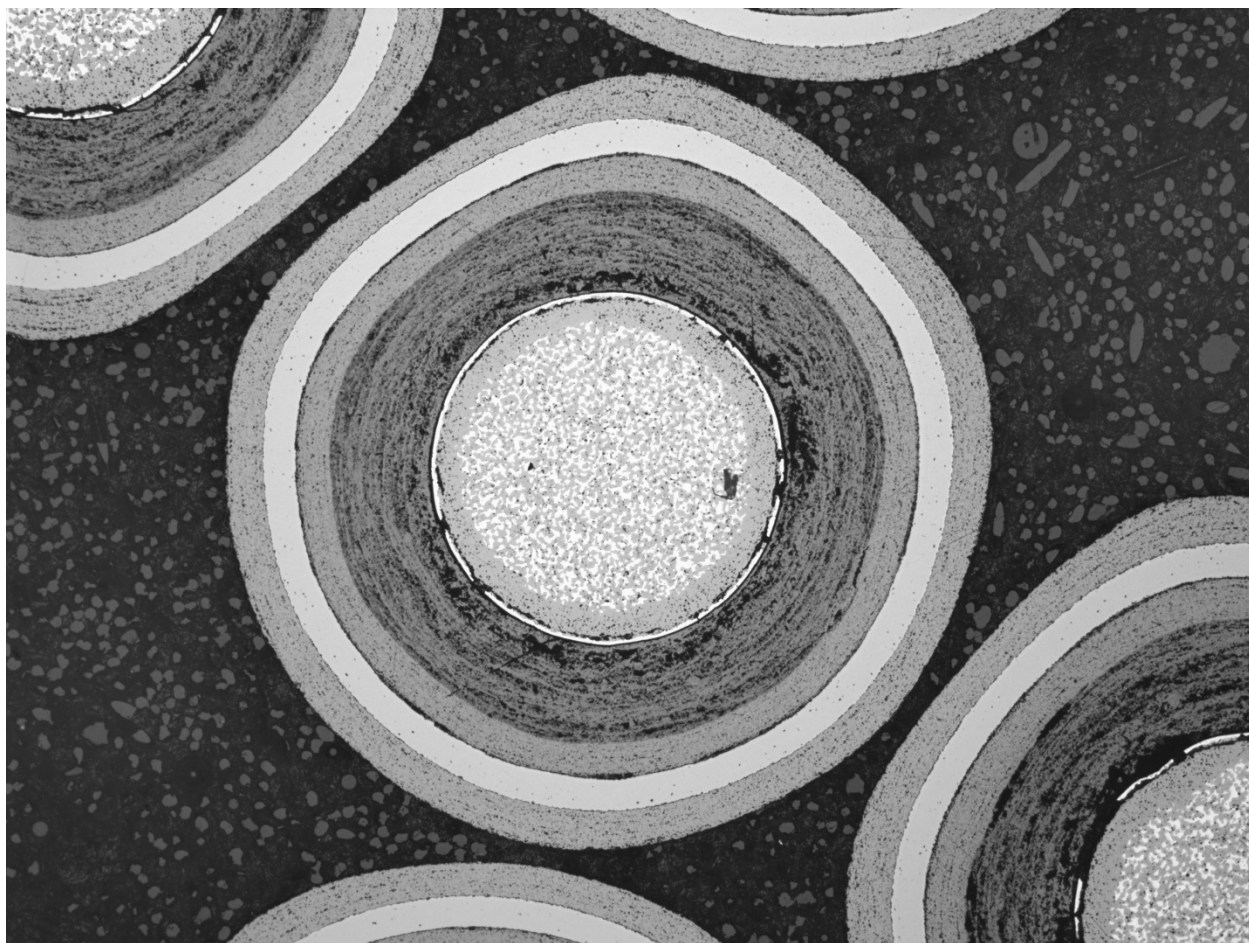
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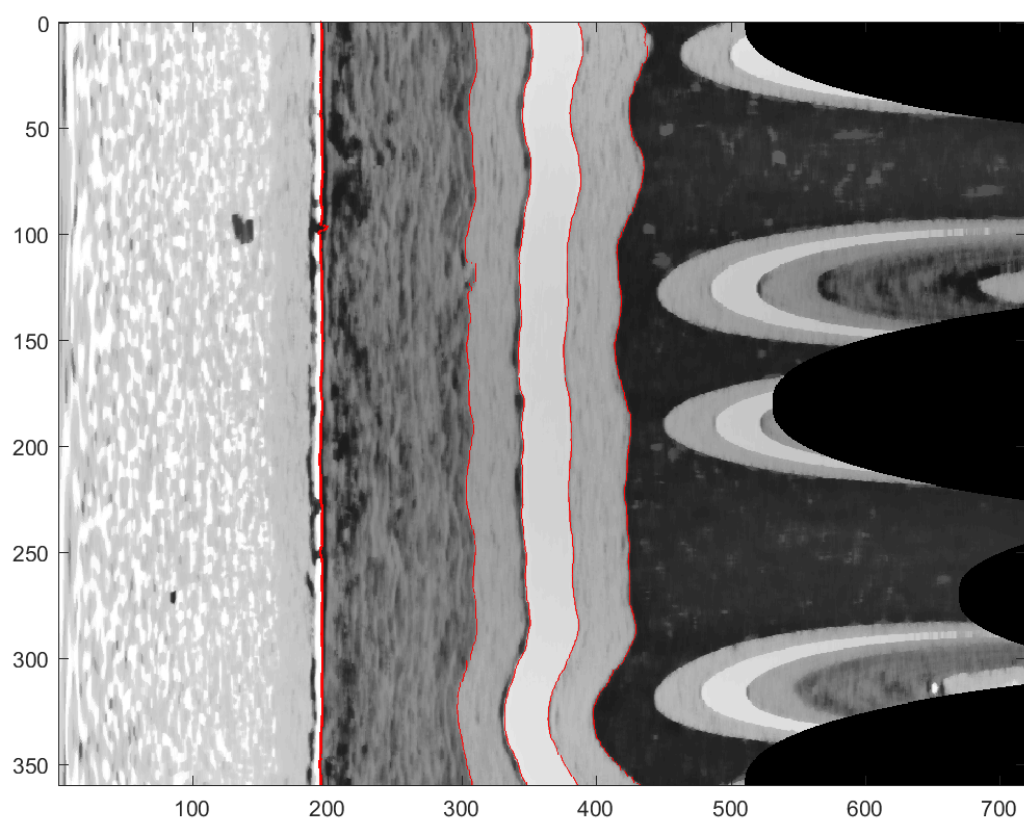
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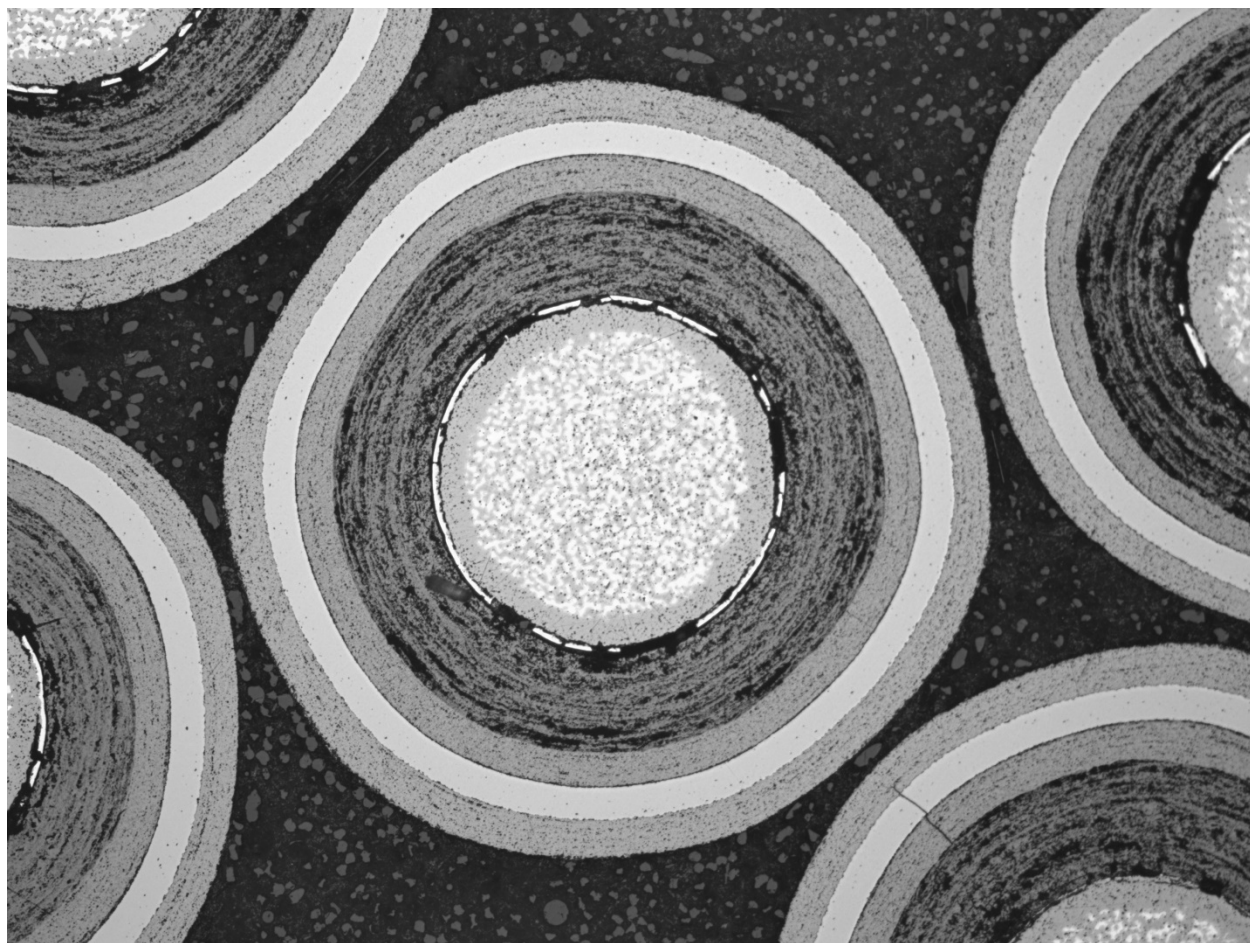


P16082301N044

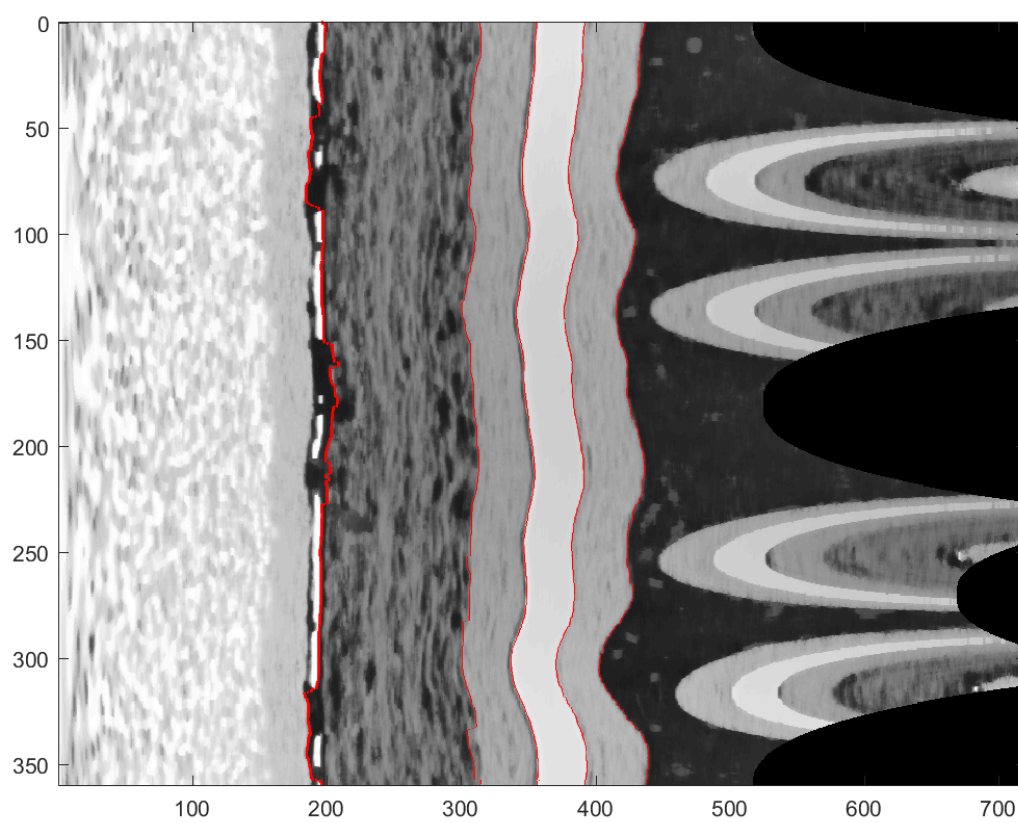


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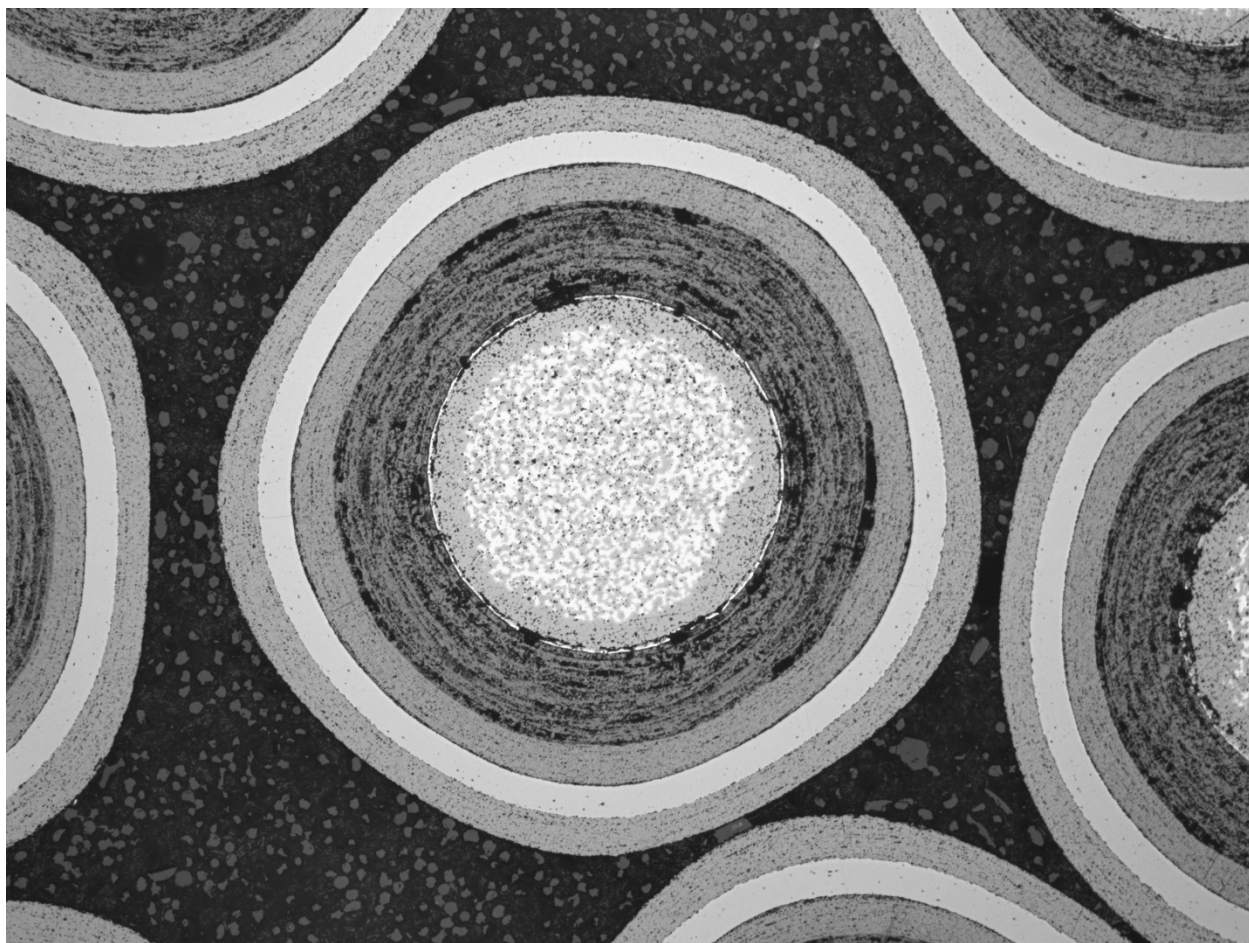




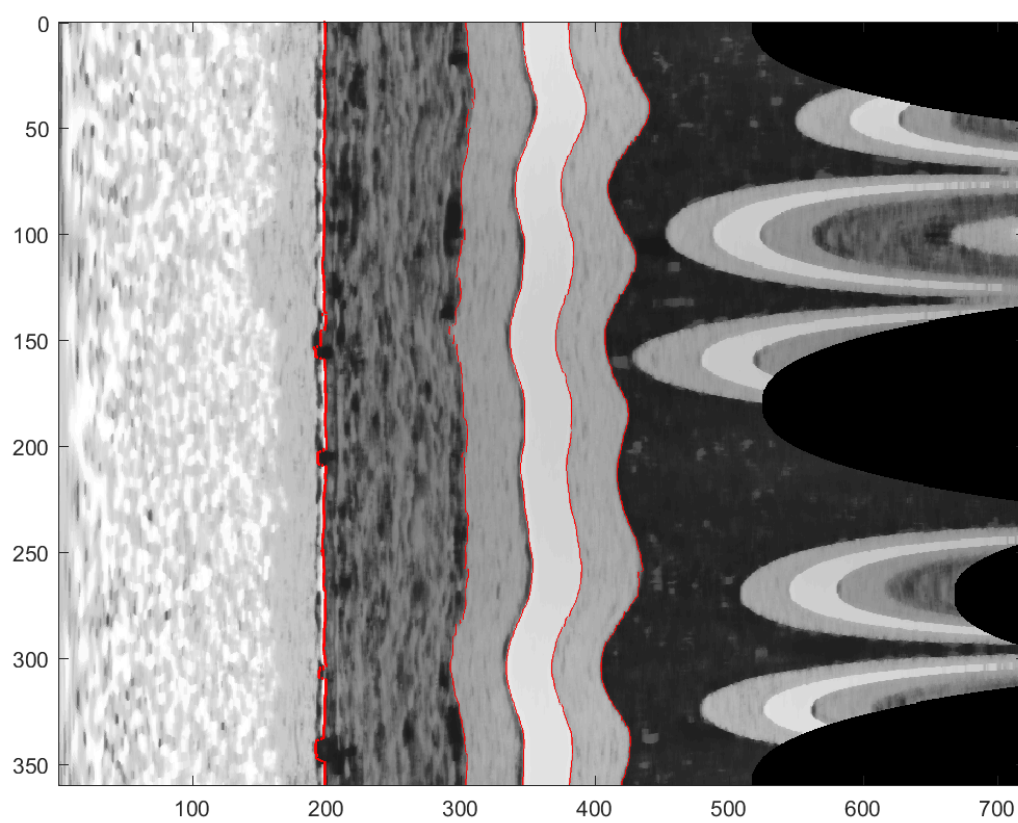
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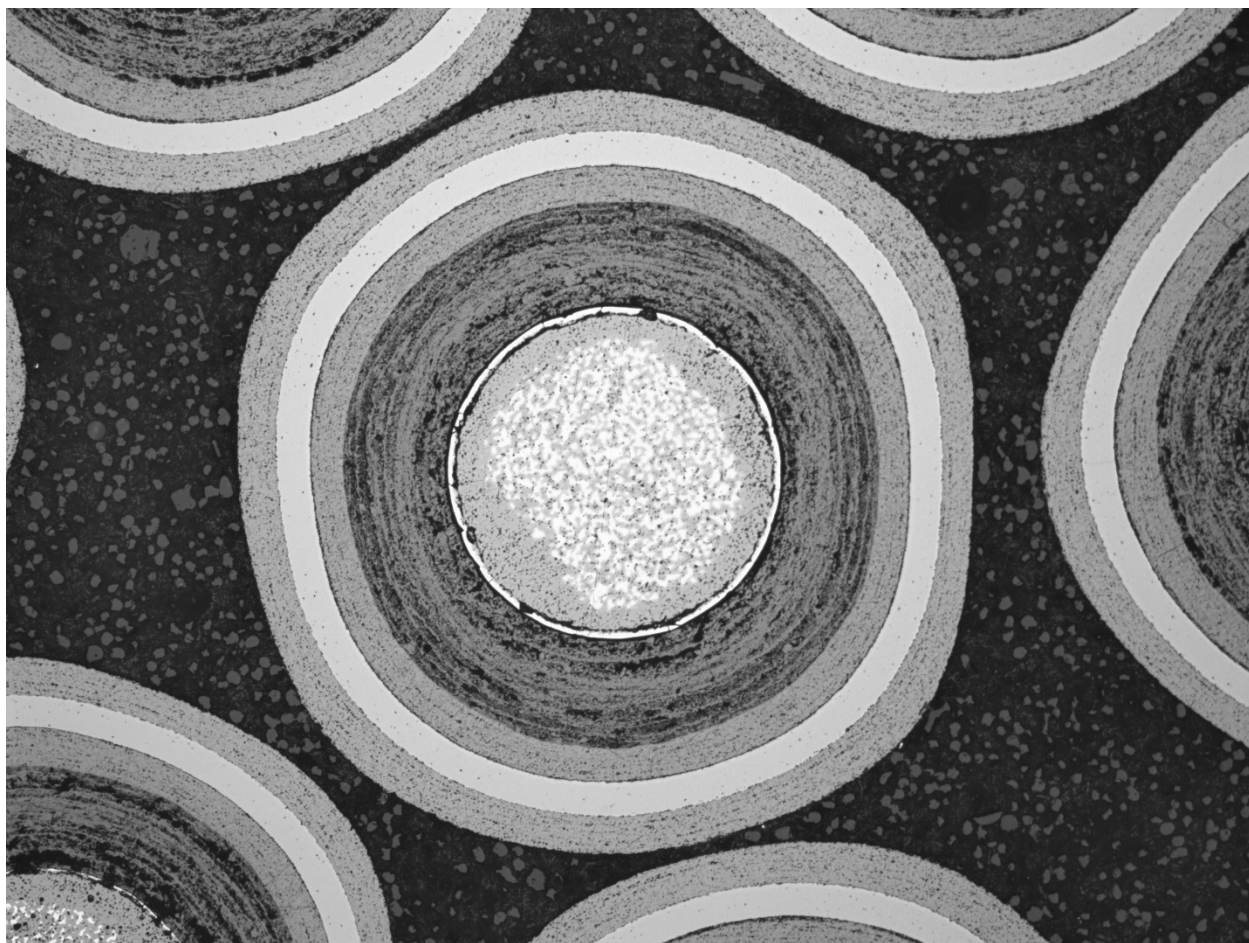
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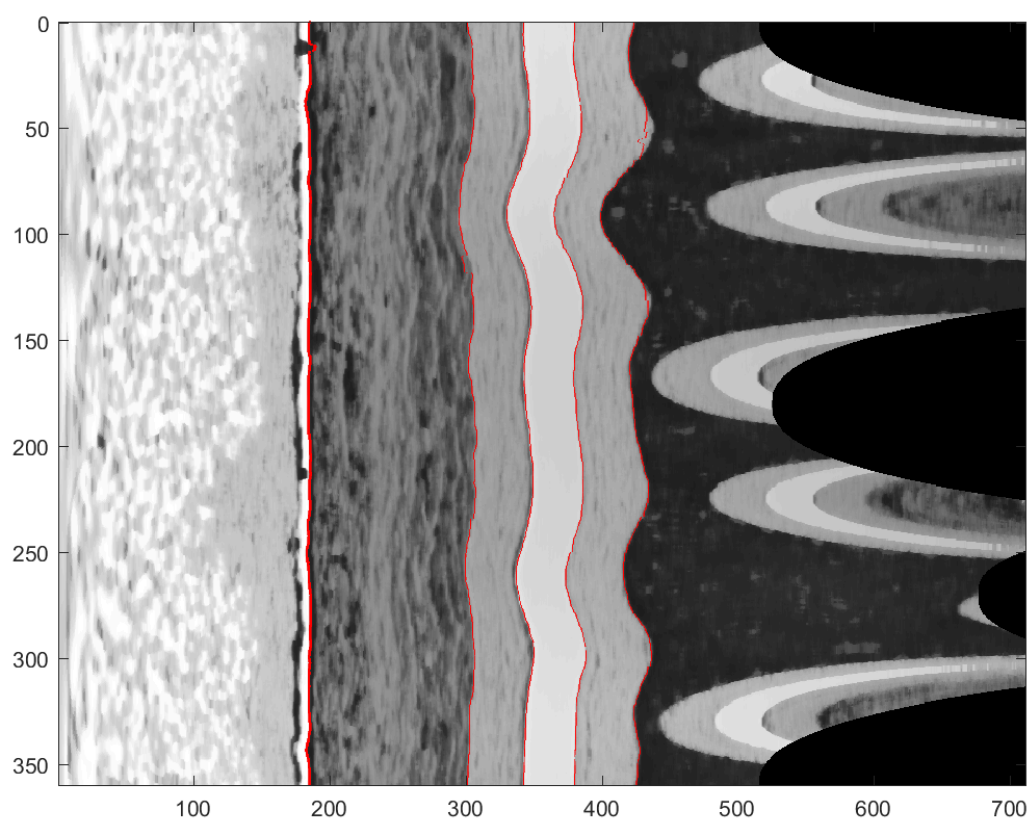
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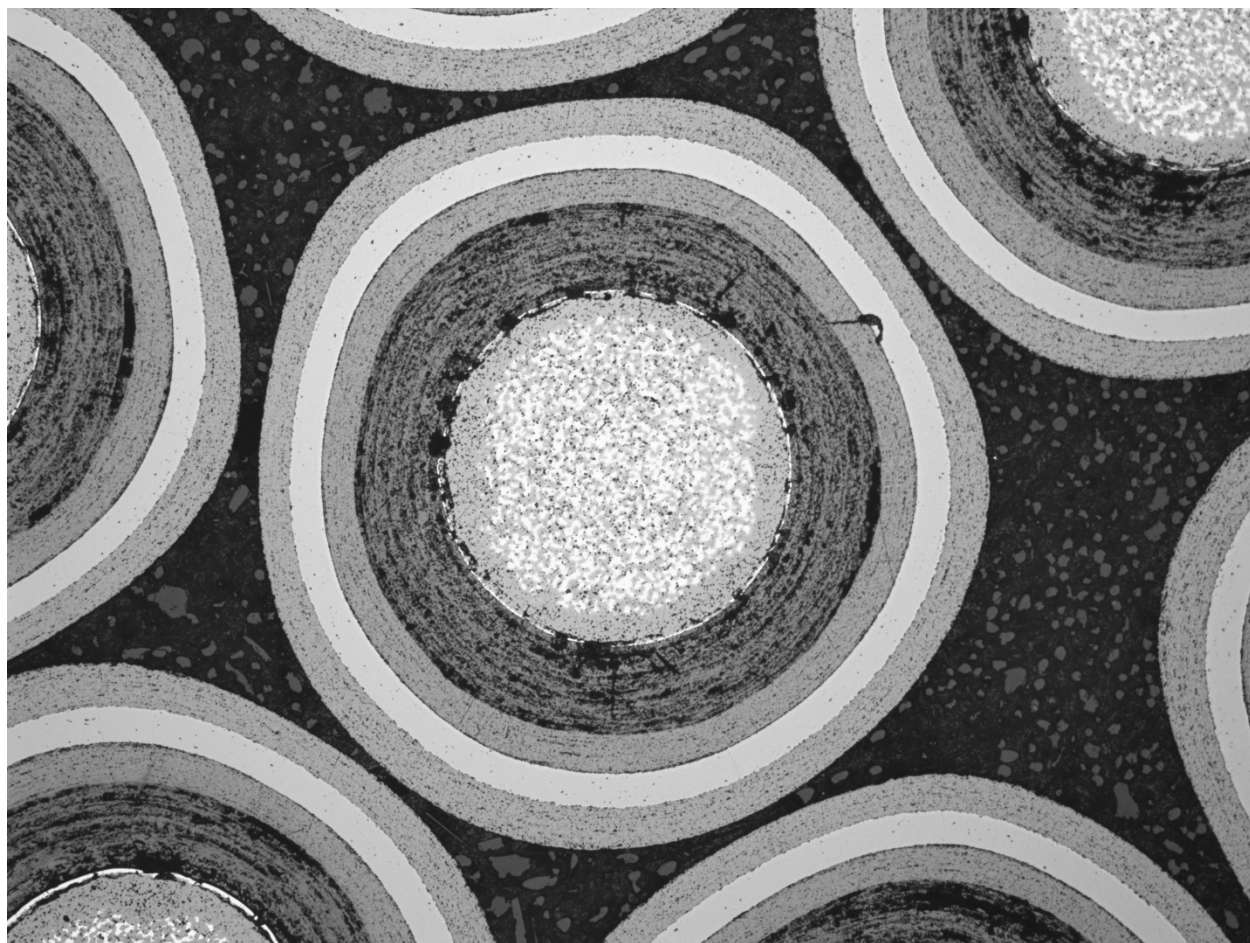


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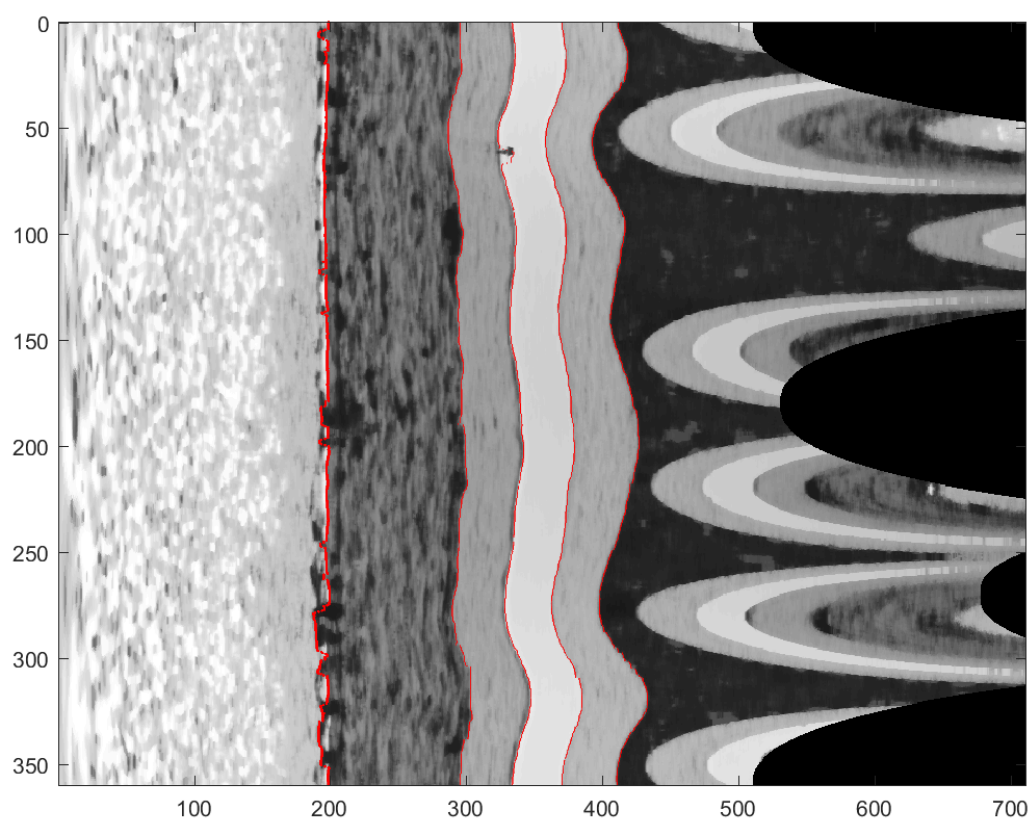
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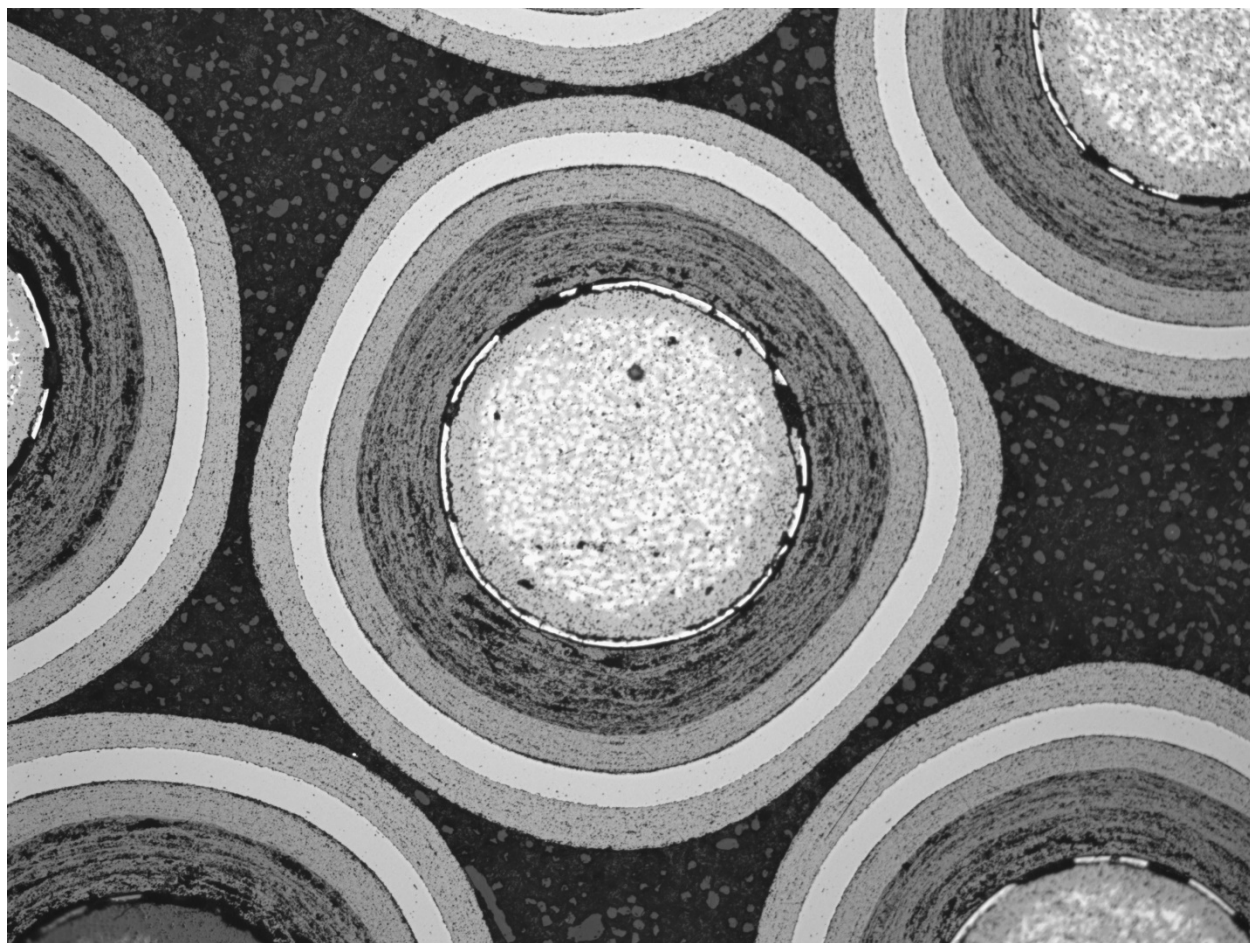


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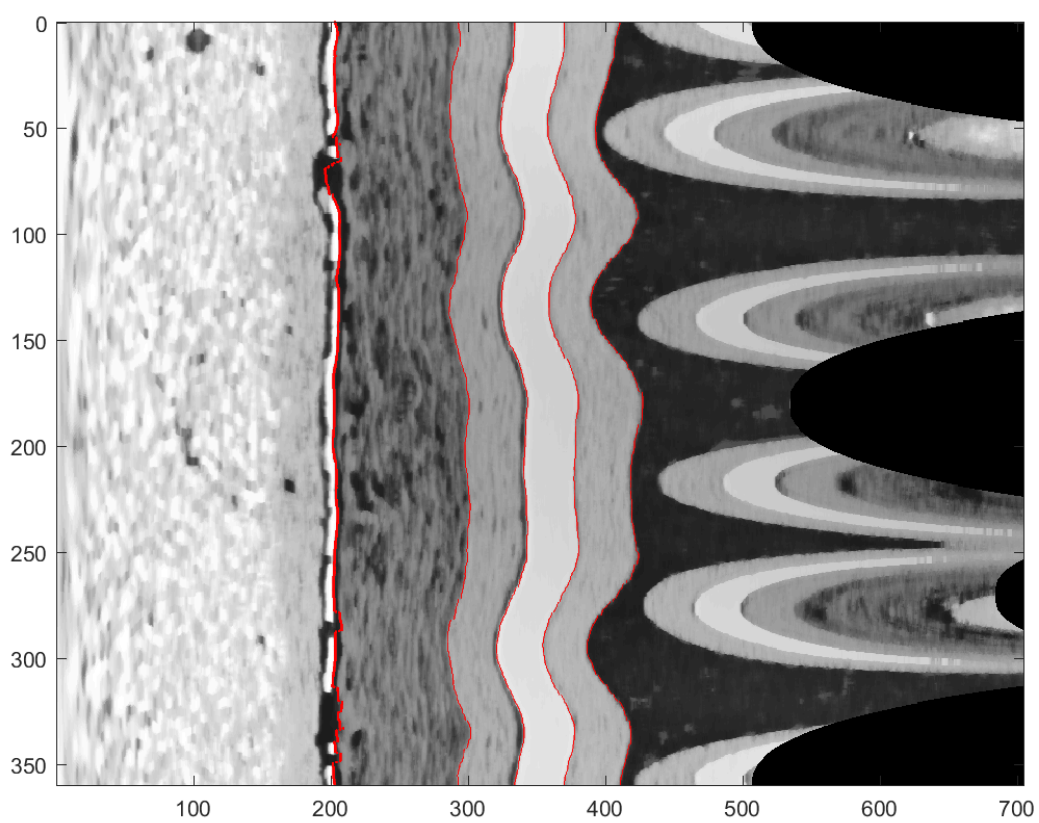




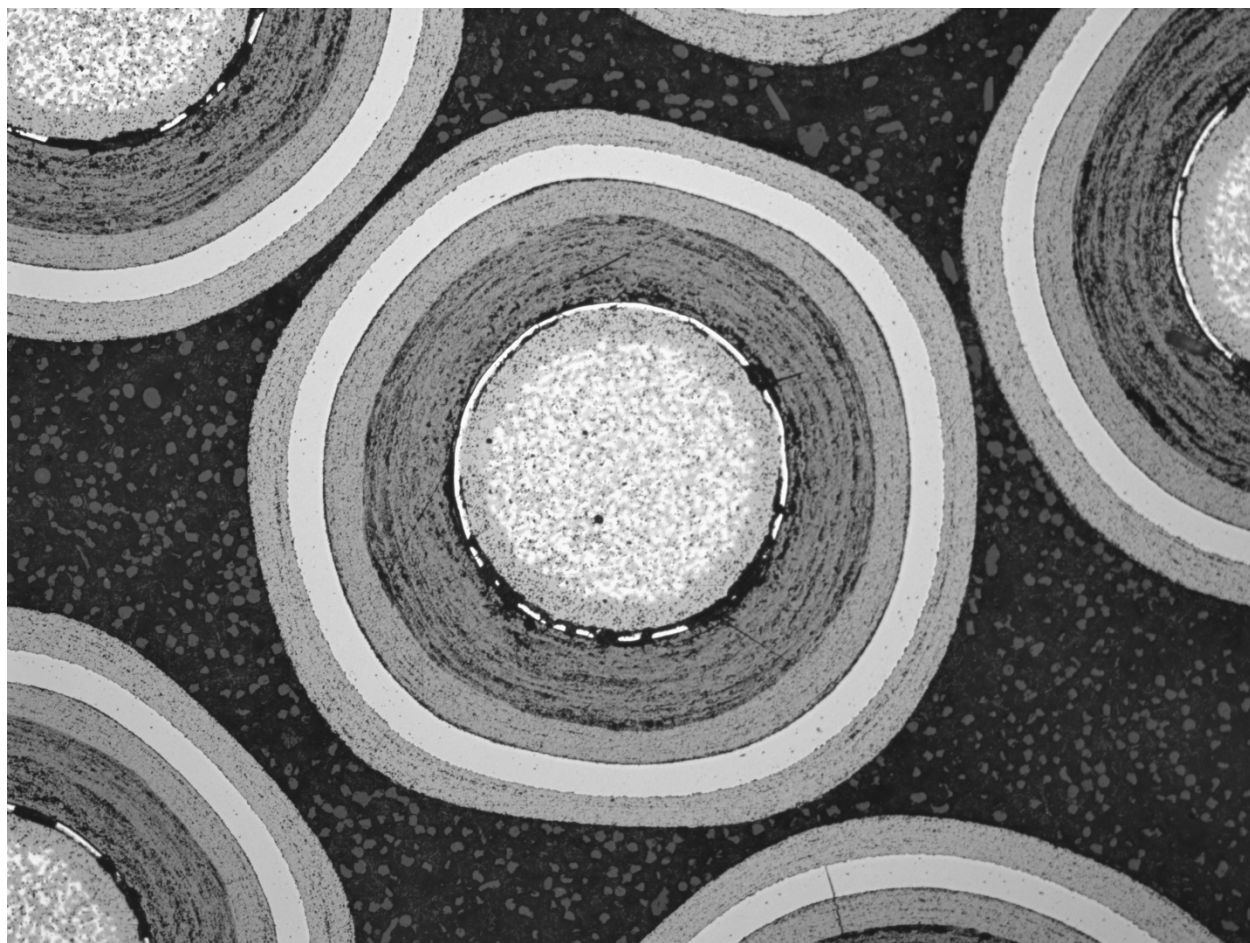
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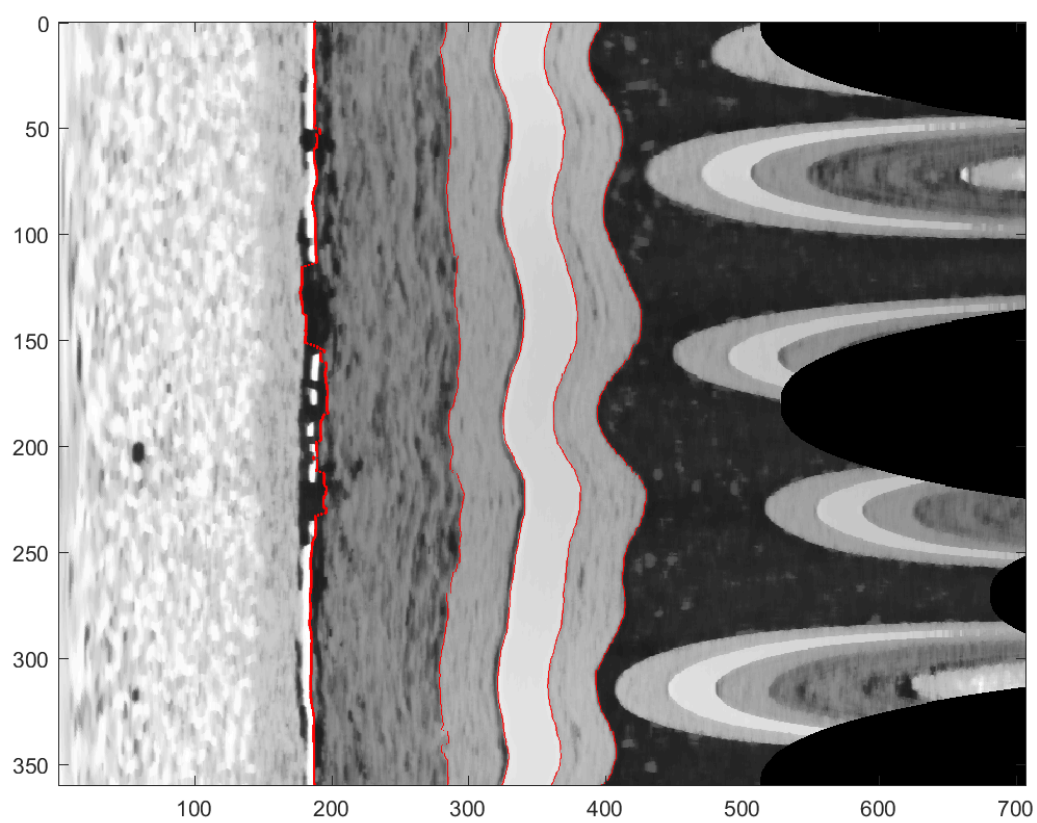
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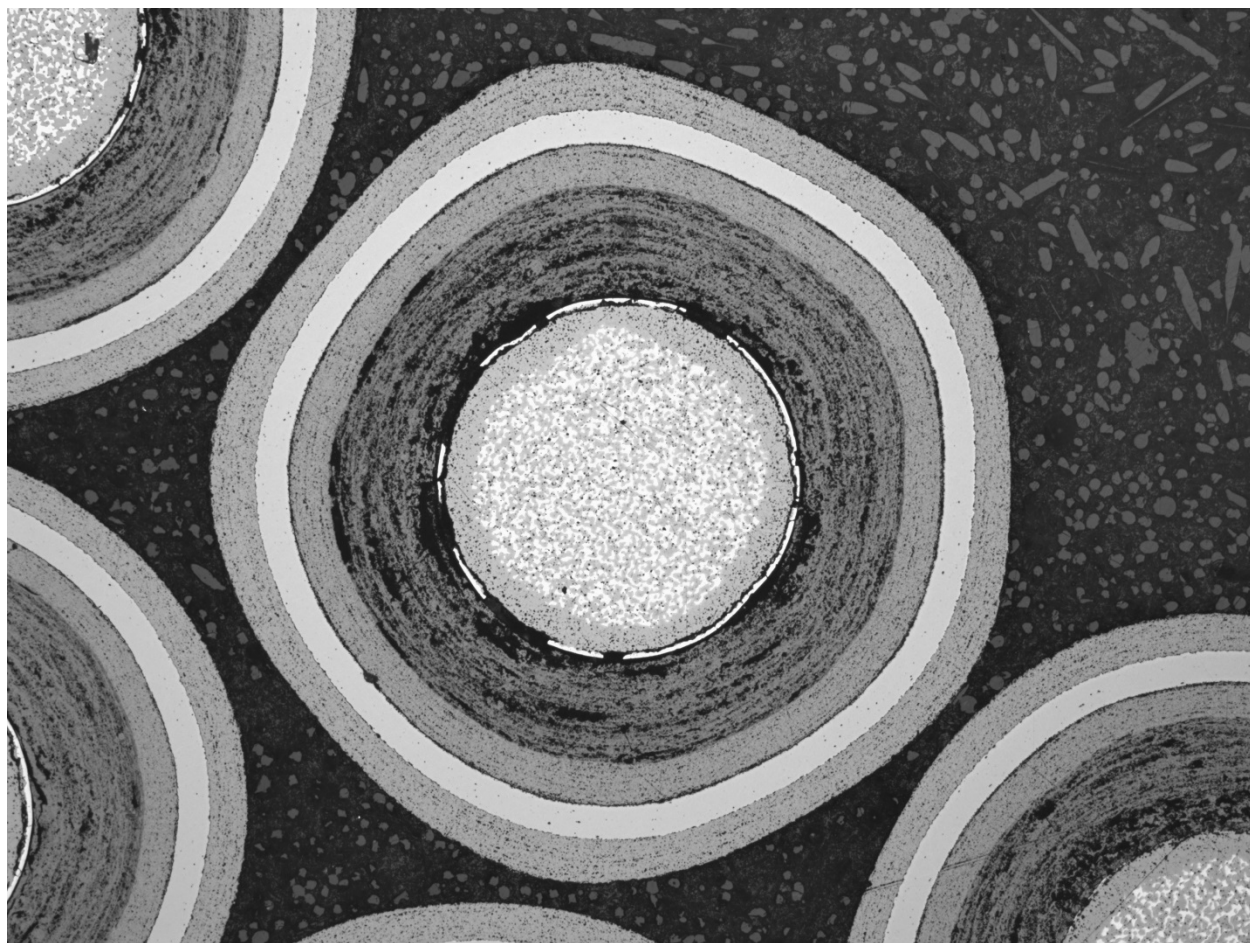
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P16082301N050

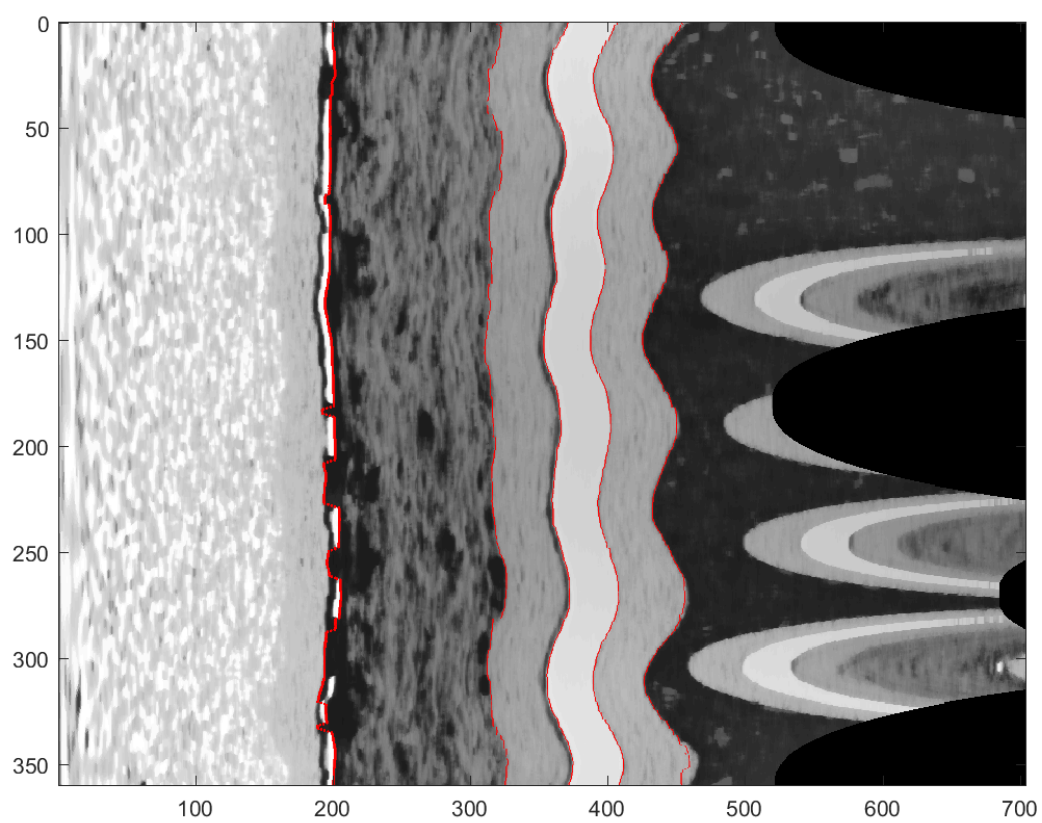


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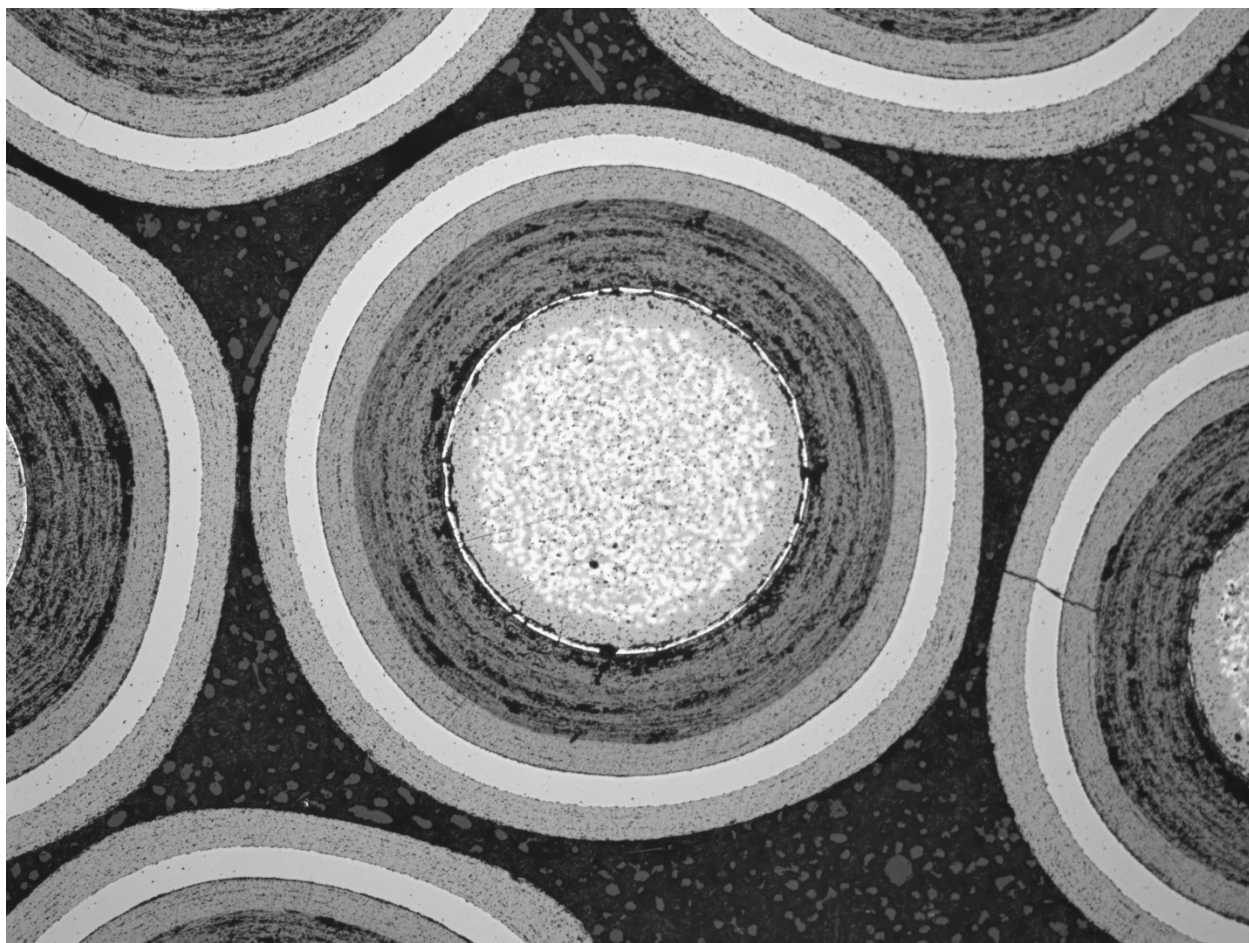
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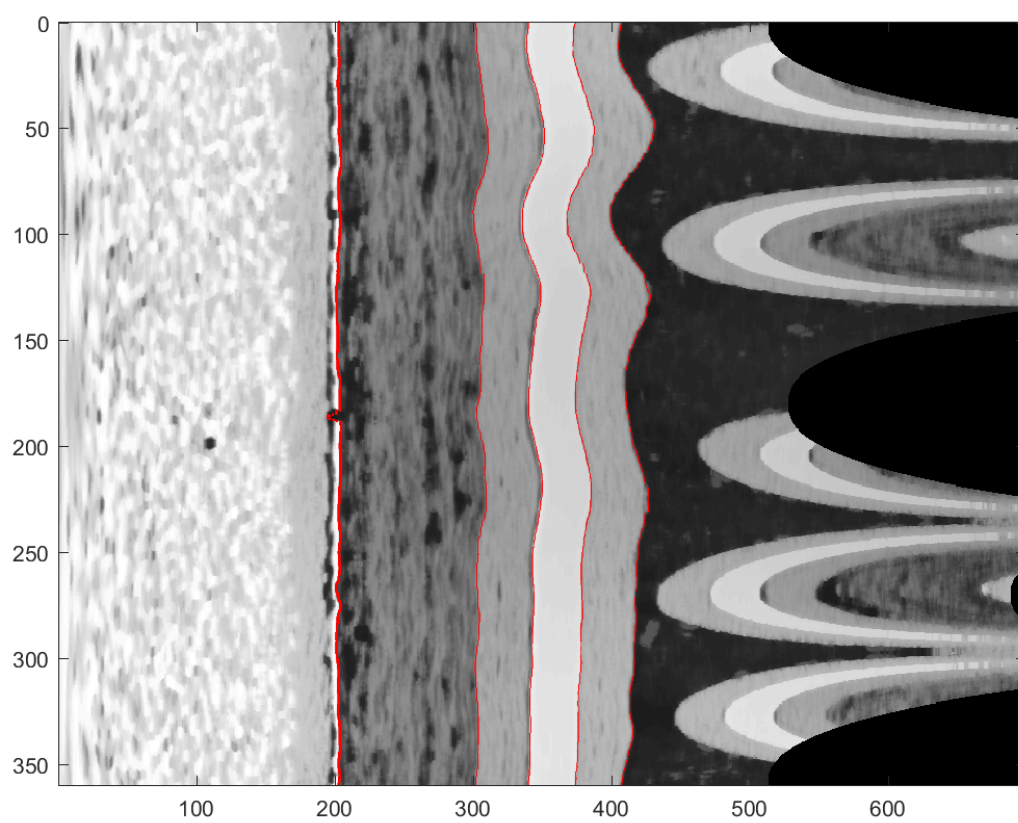


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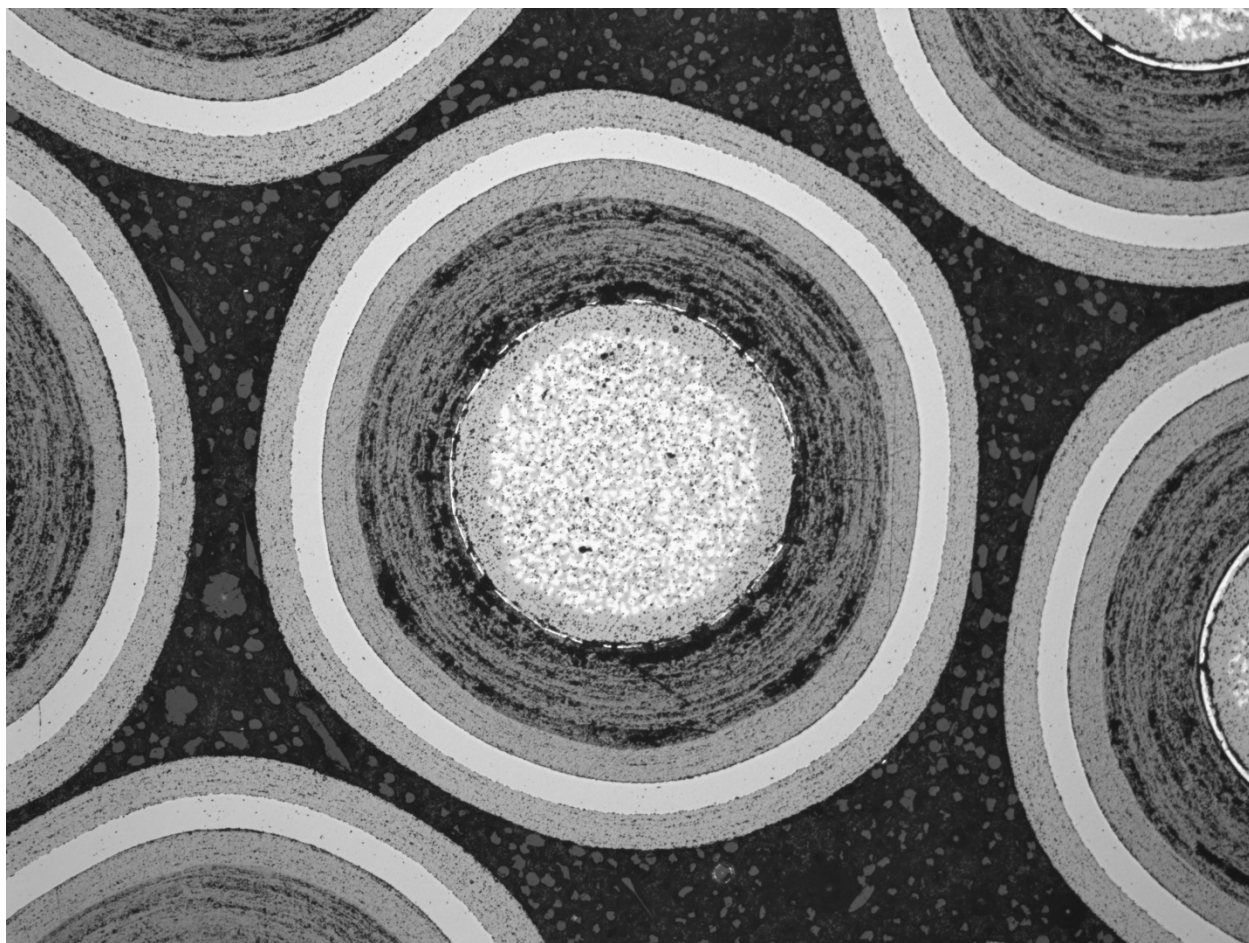




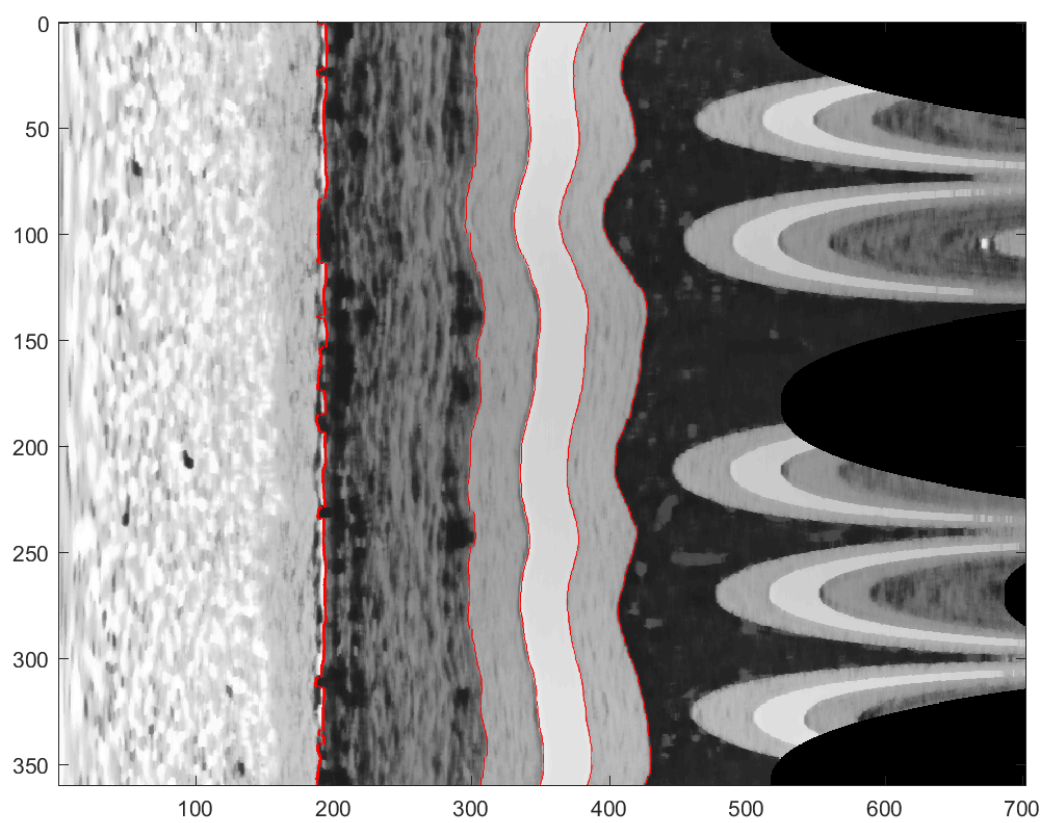
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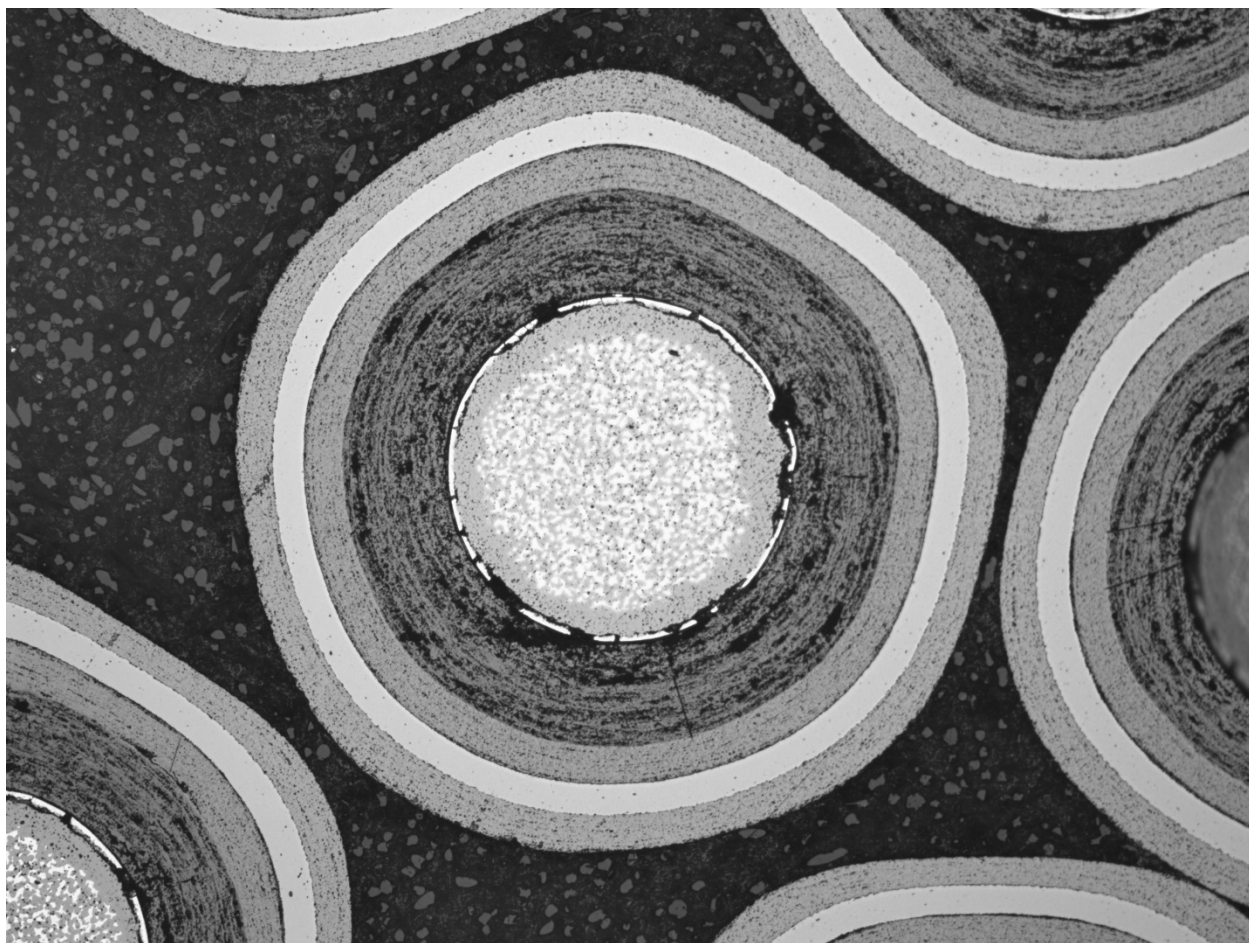
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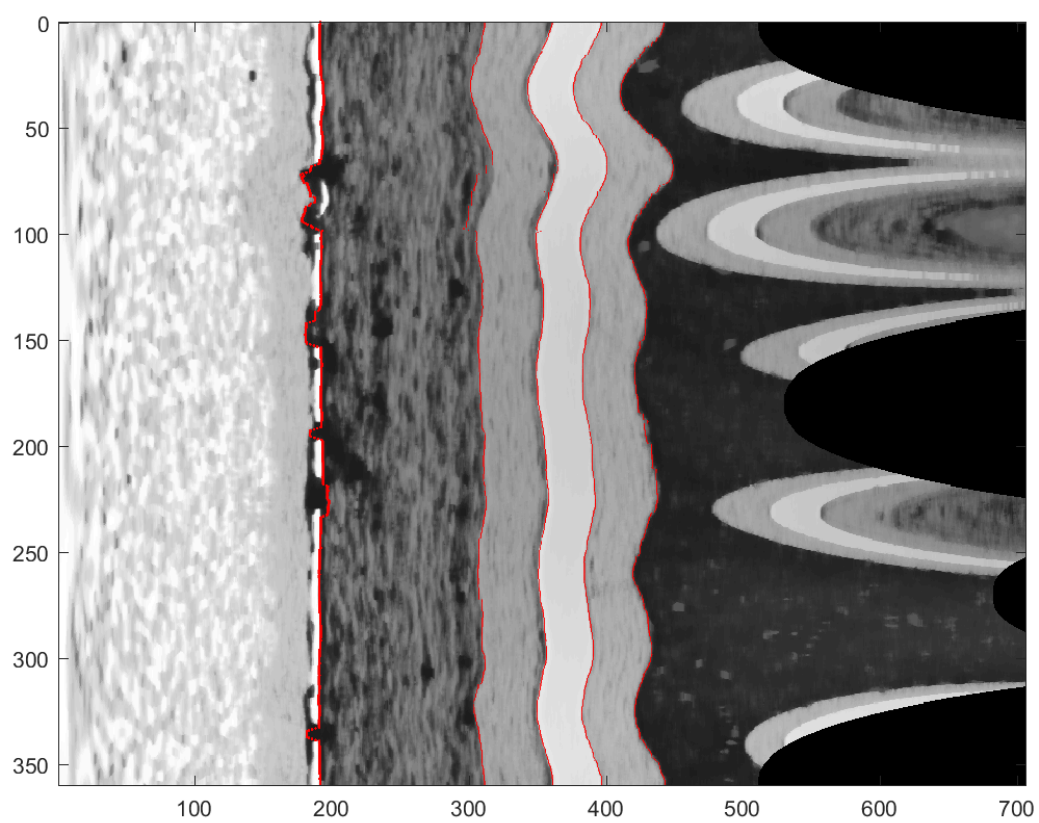
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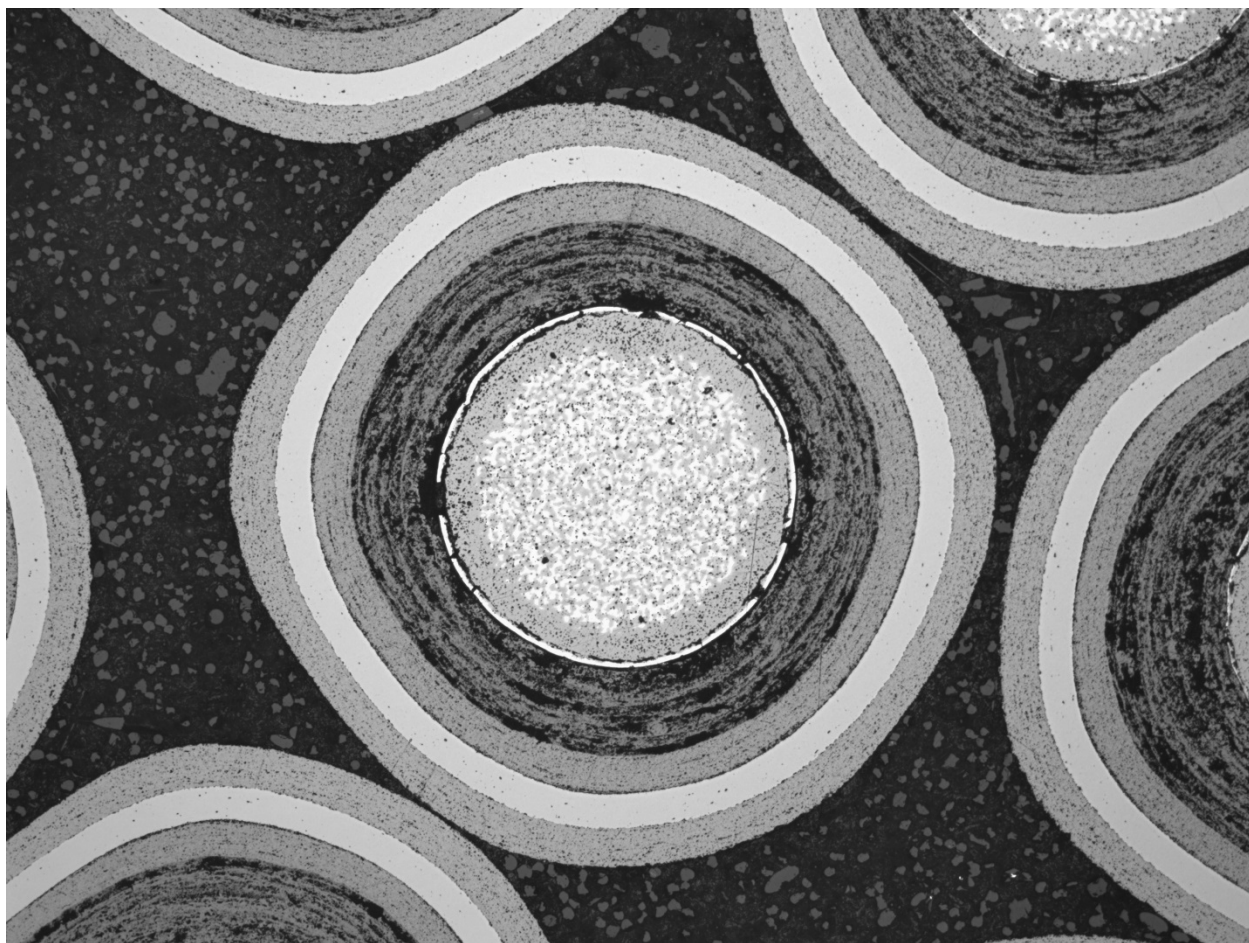


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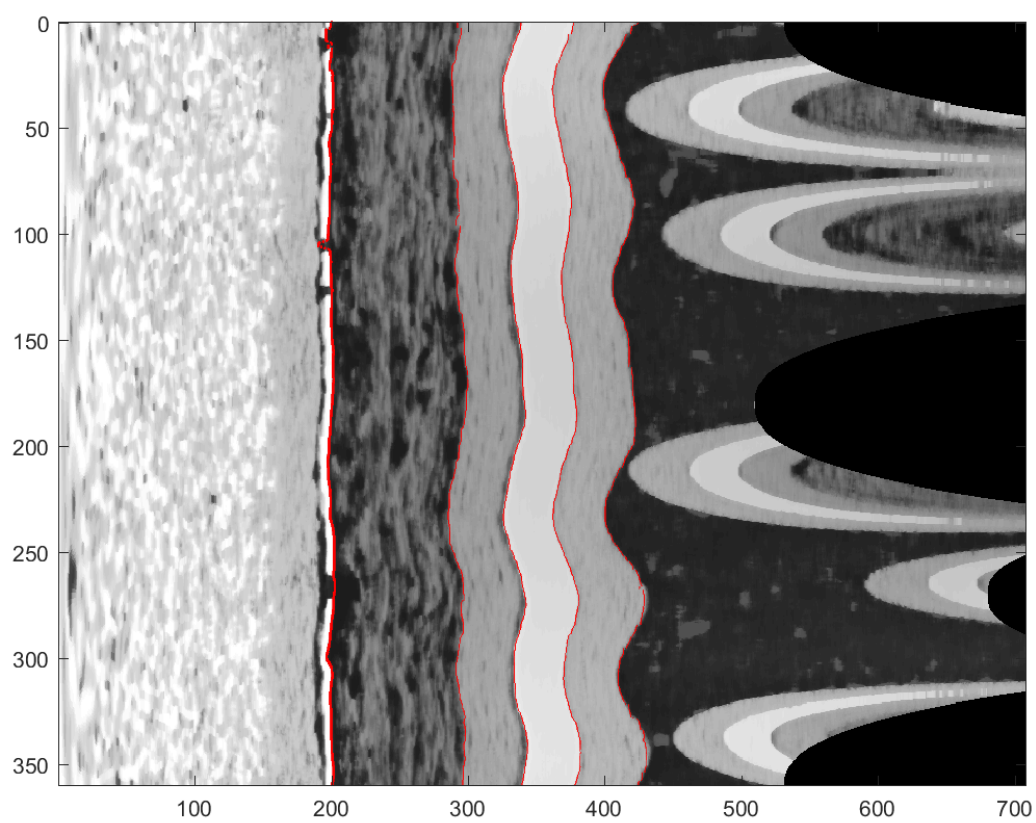
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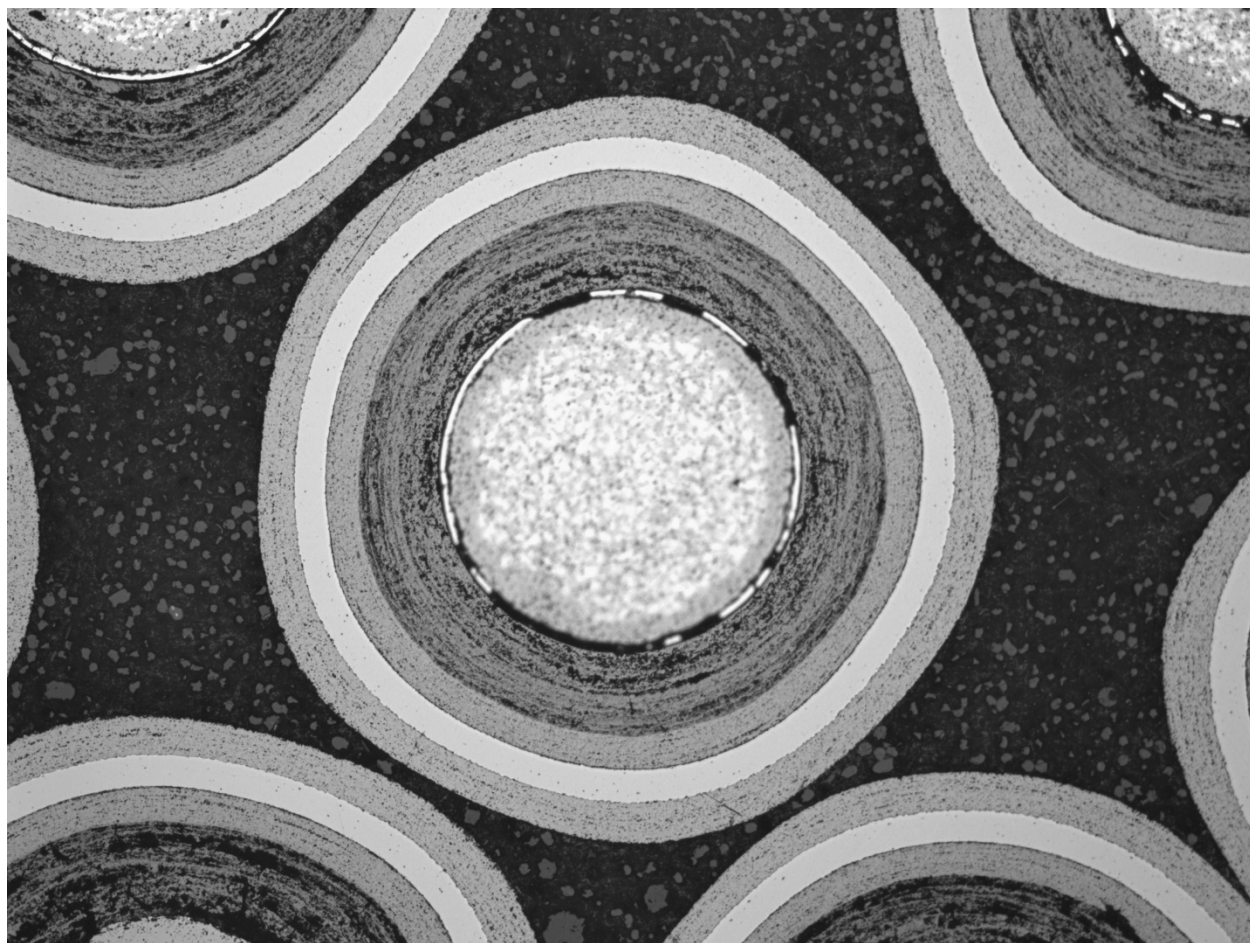


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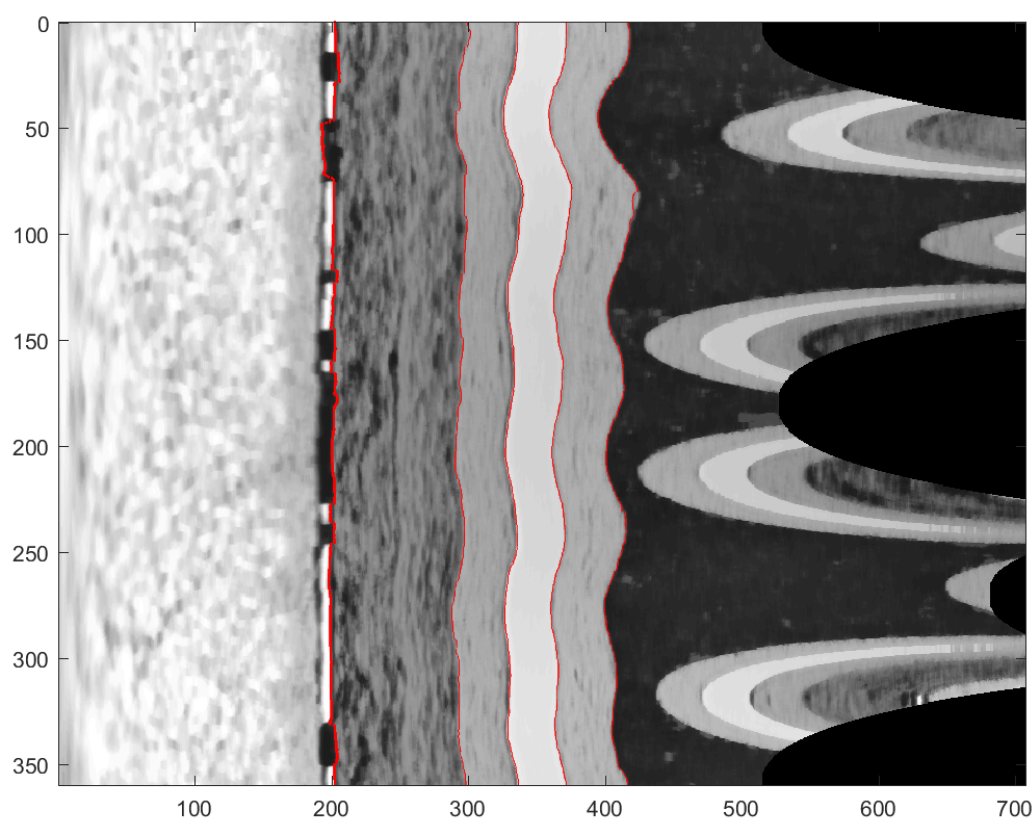




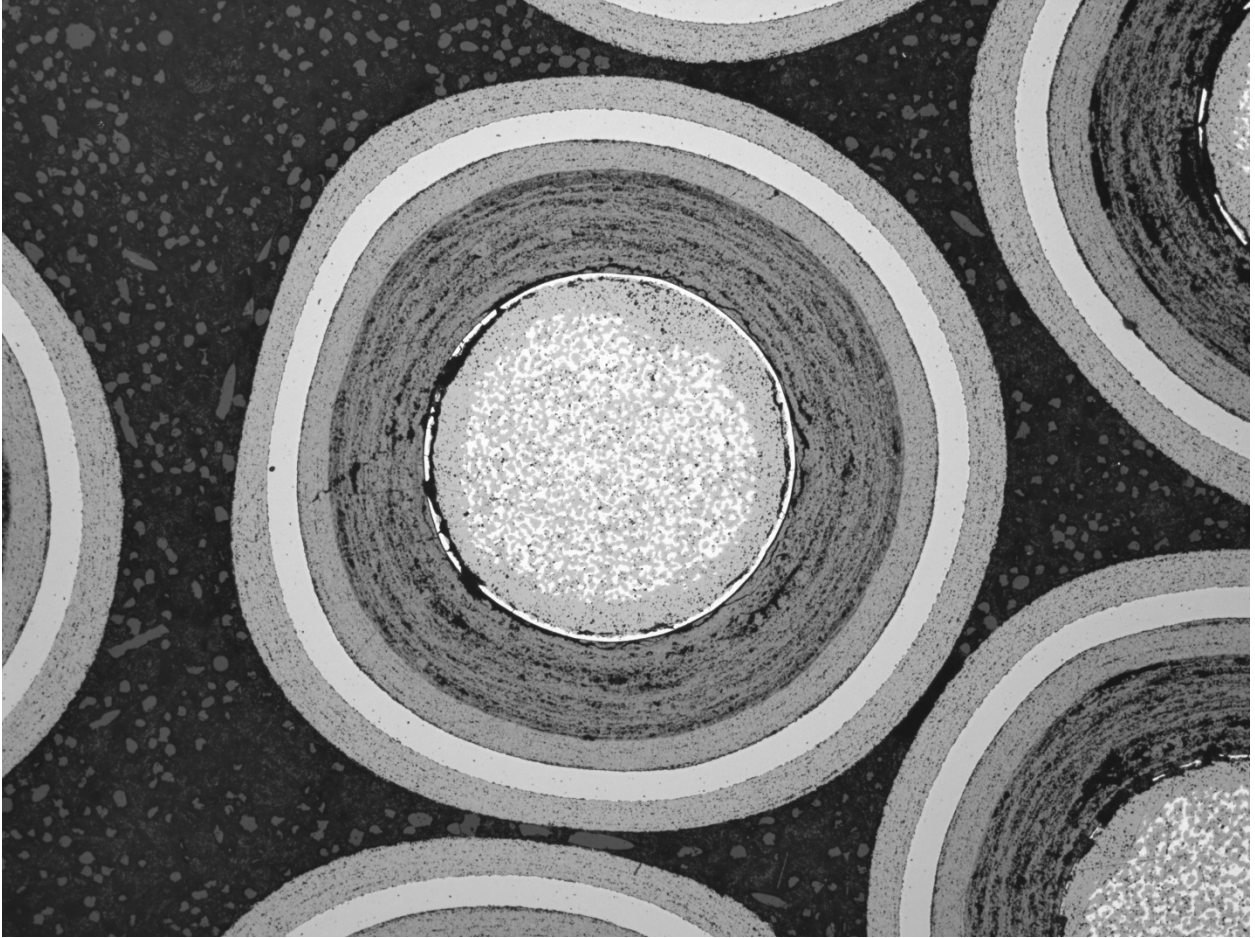
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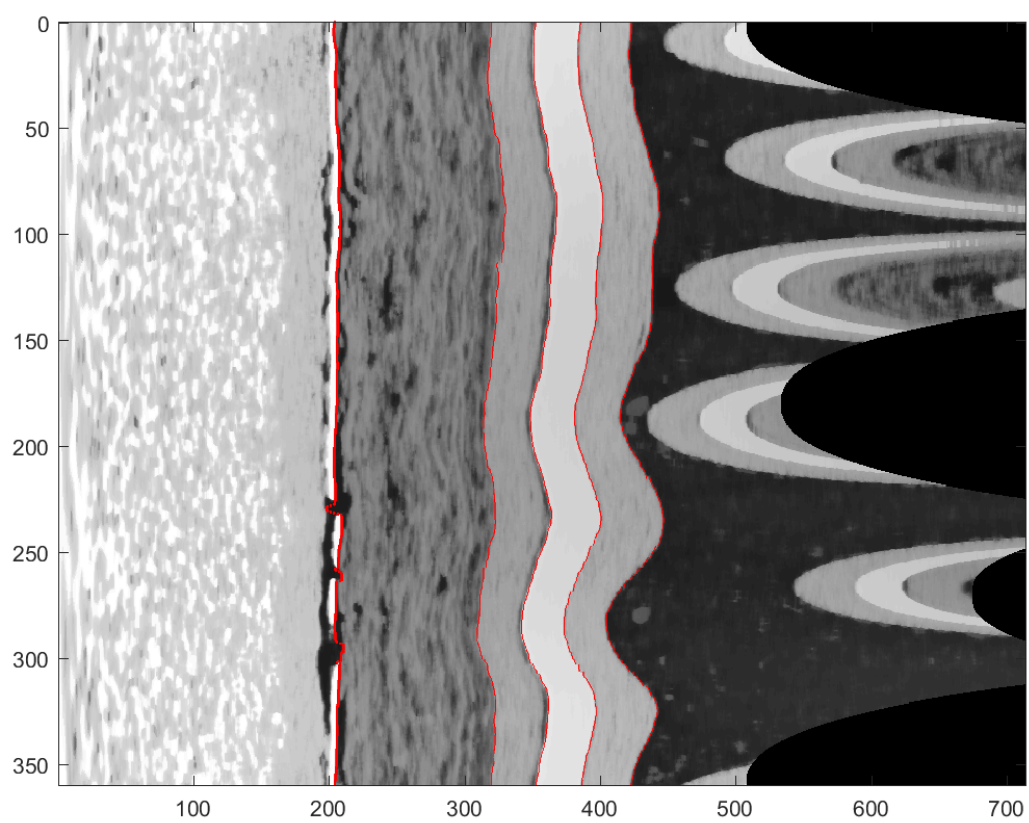
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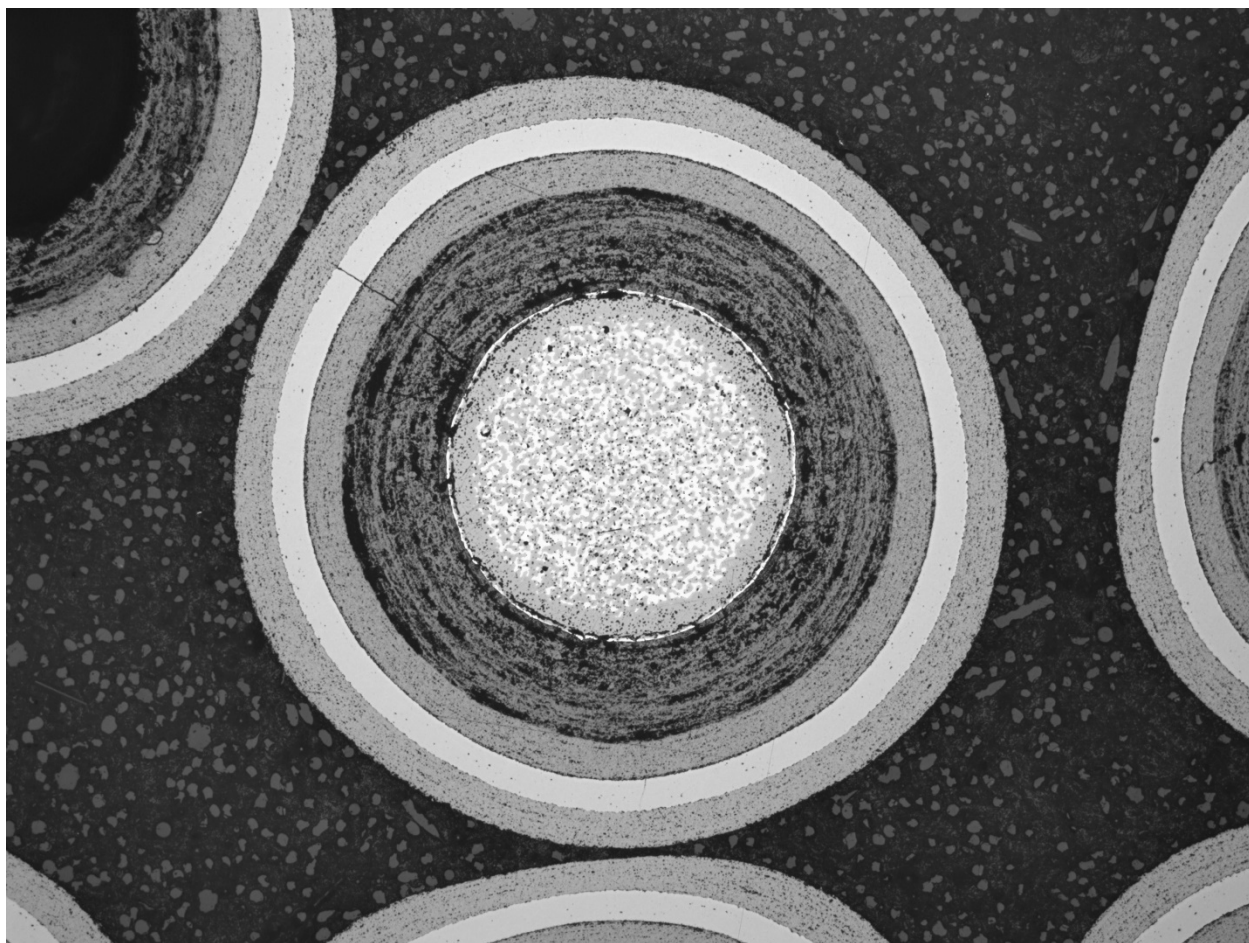
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P16082301N058

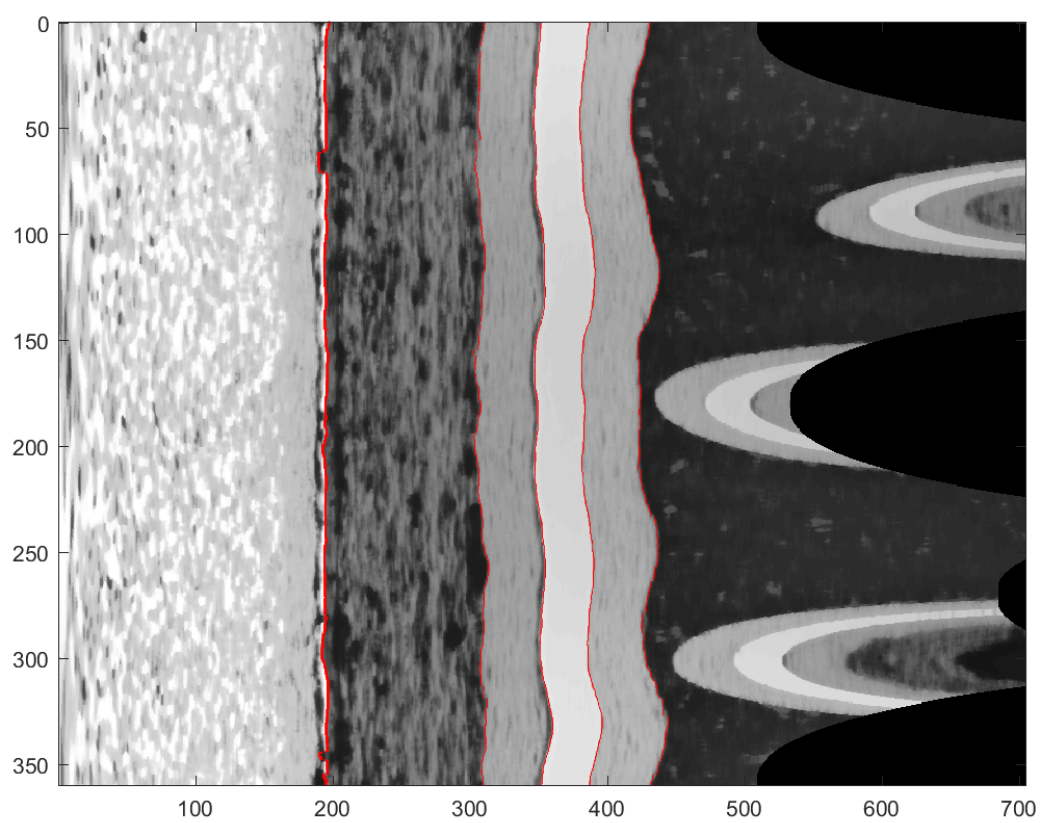


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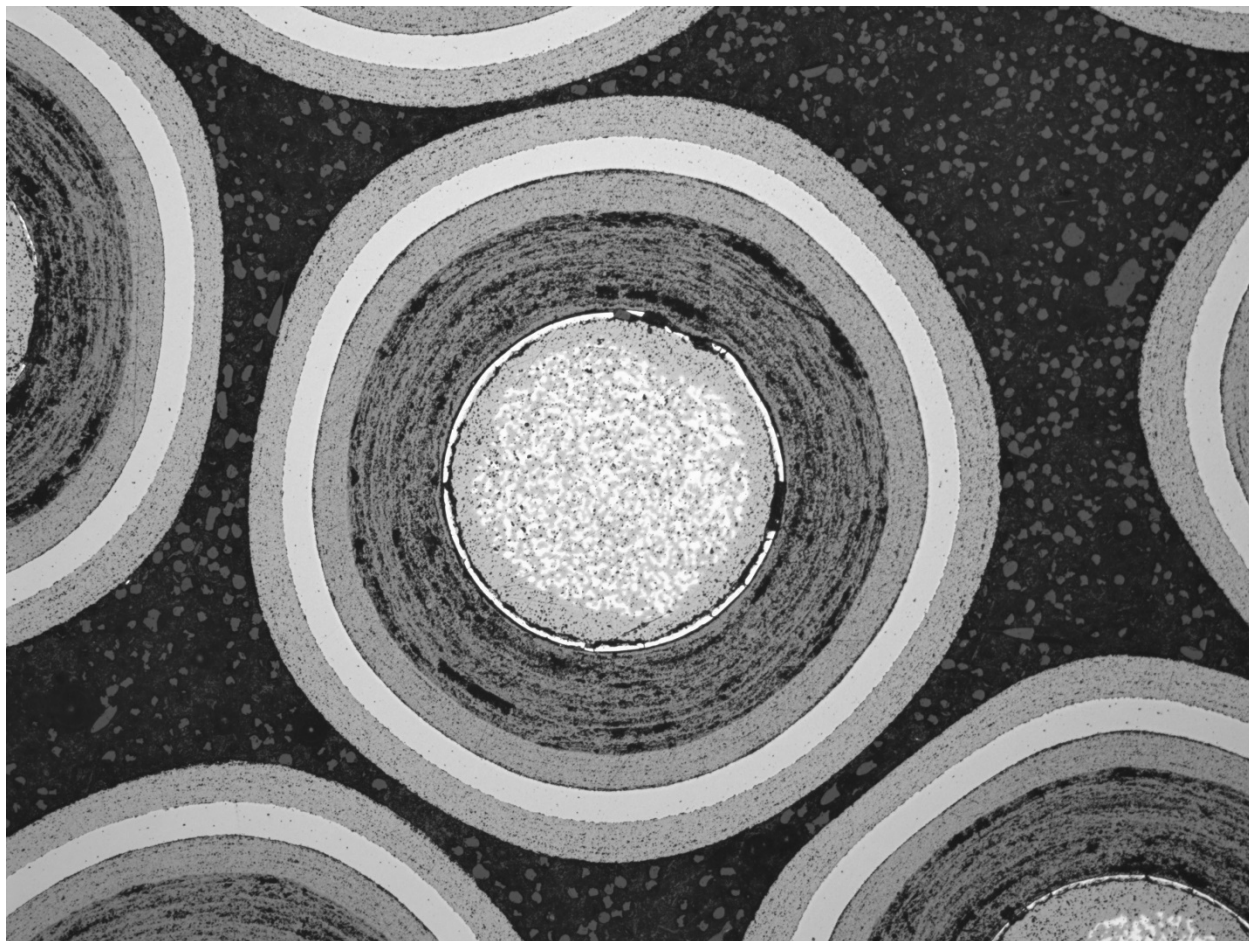
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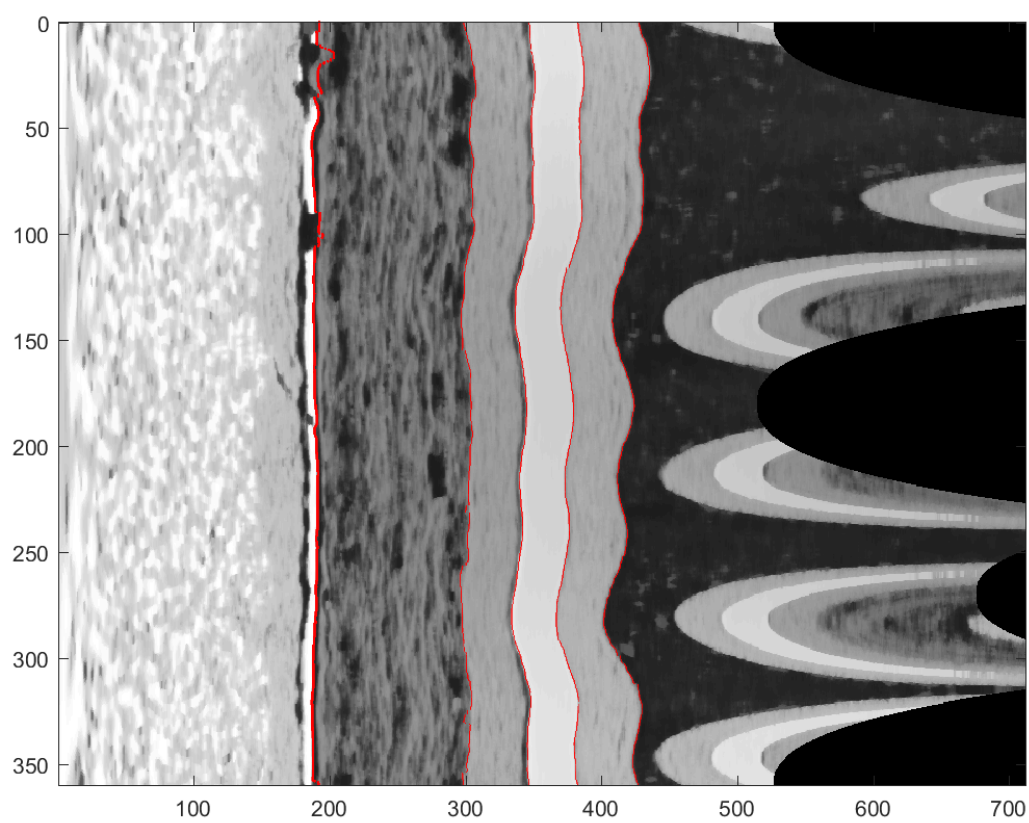


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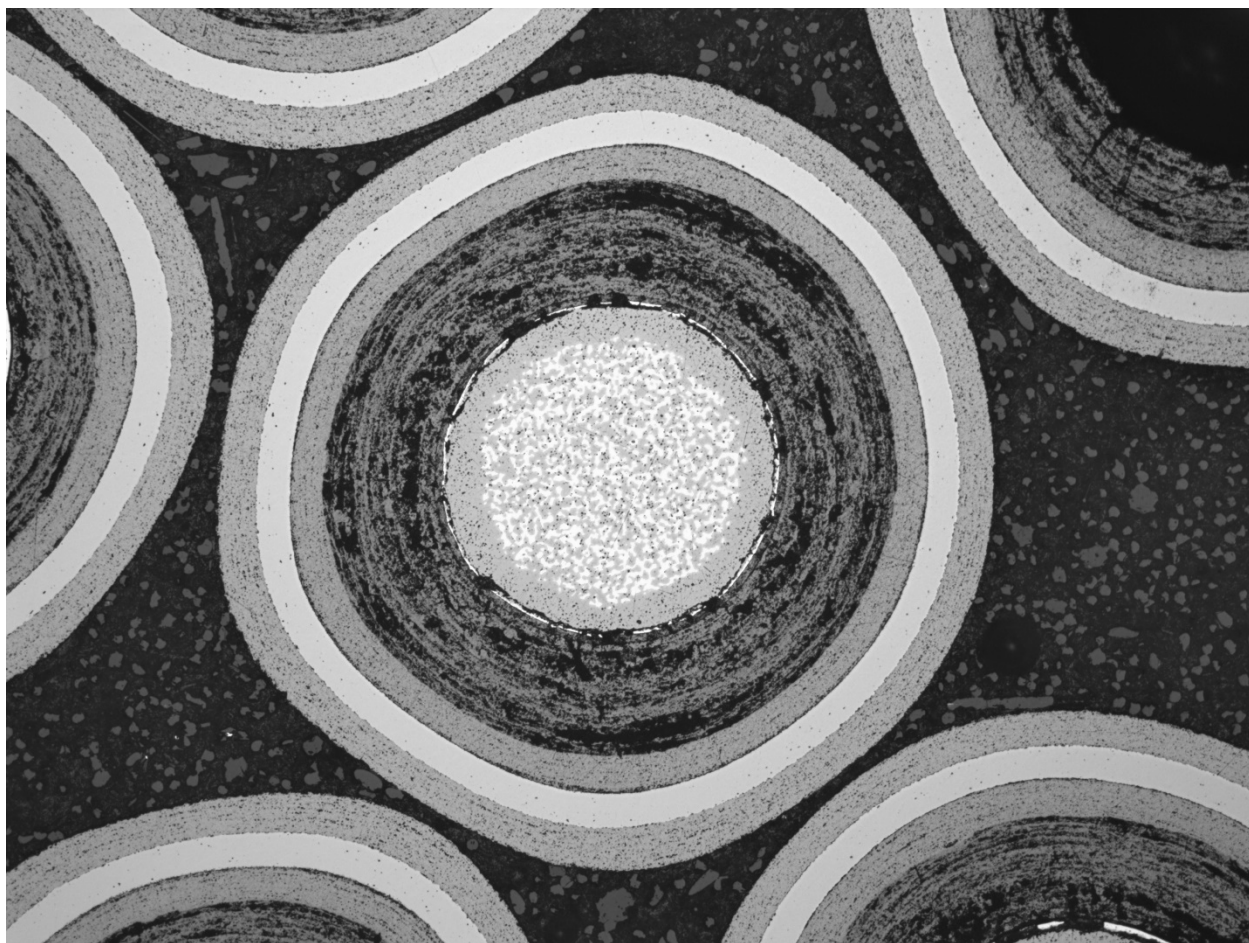




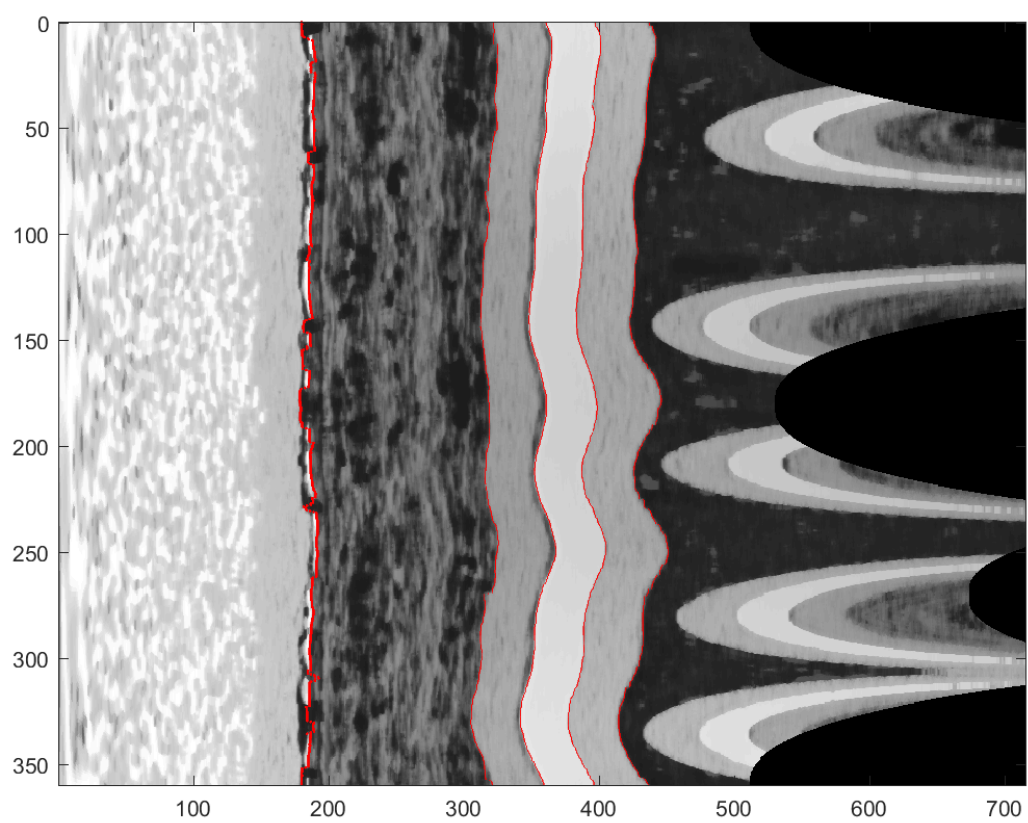
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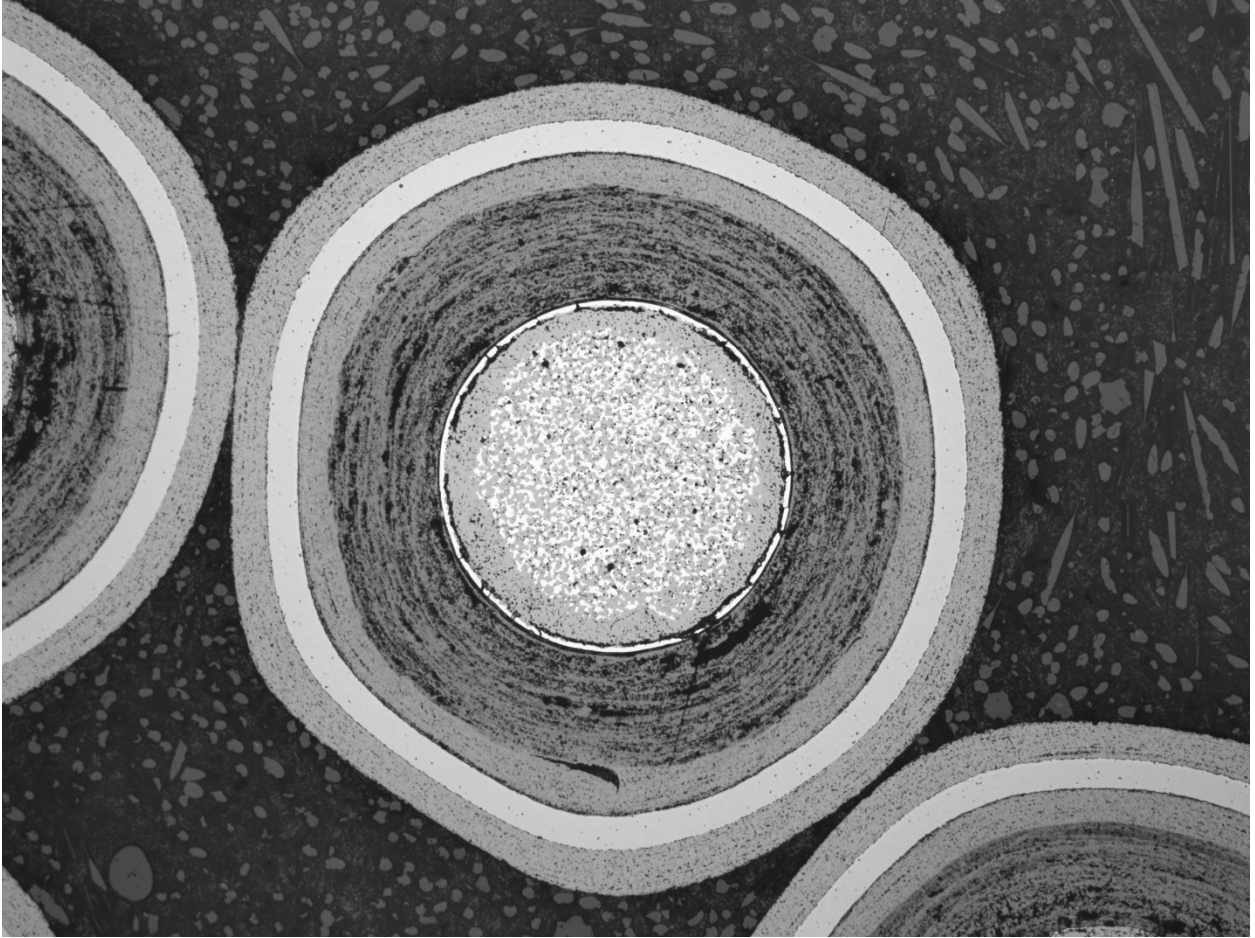
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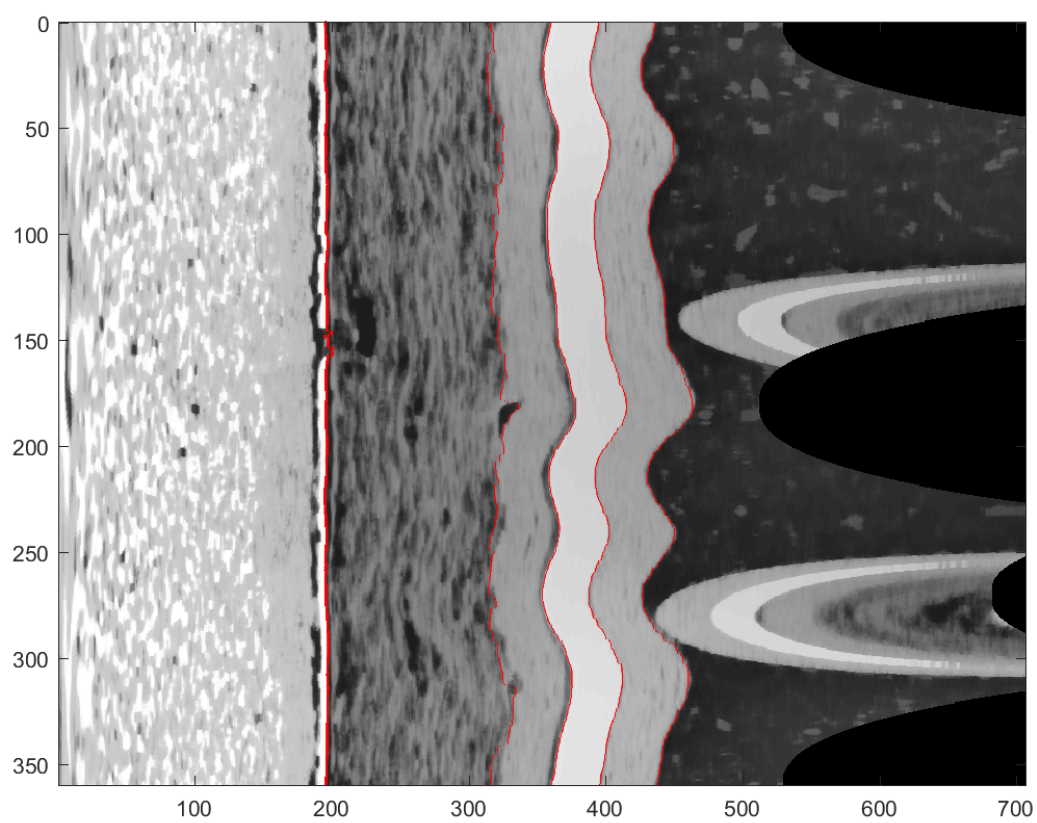
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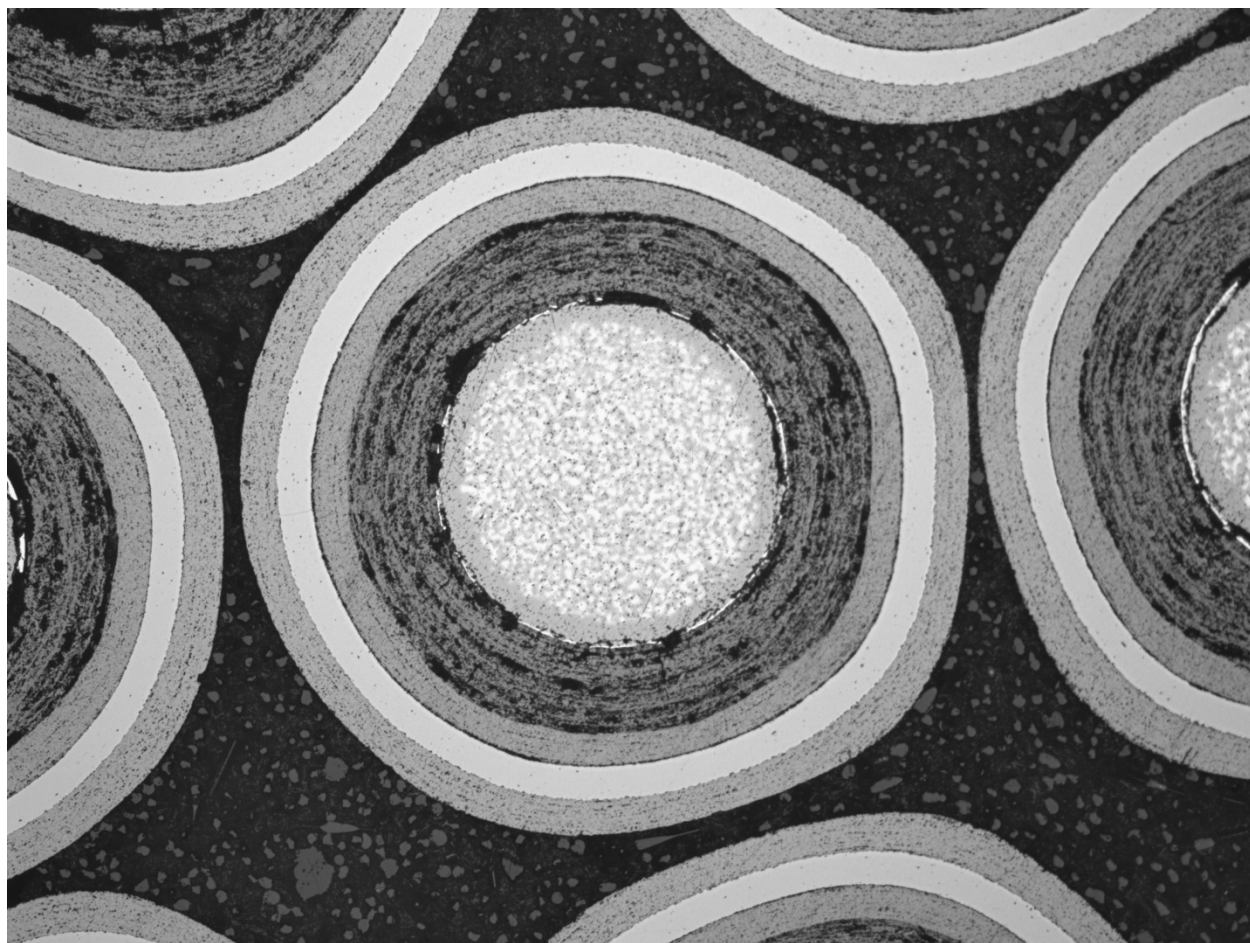


P16082301N065



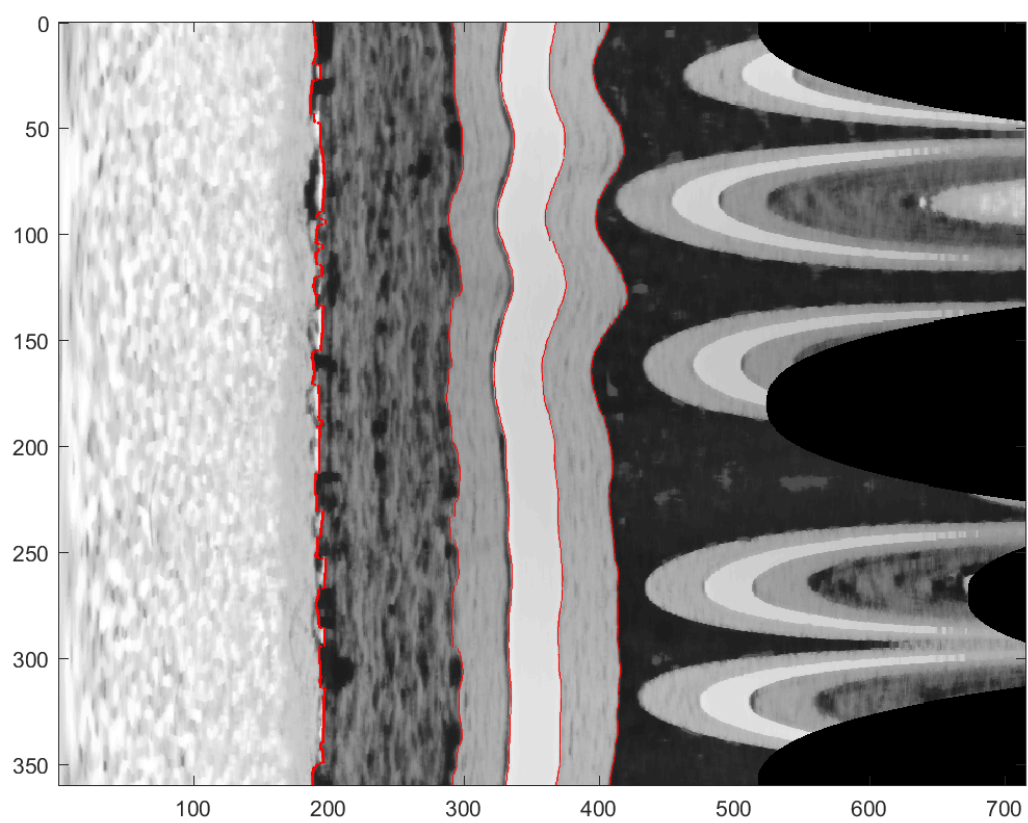
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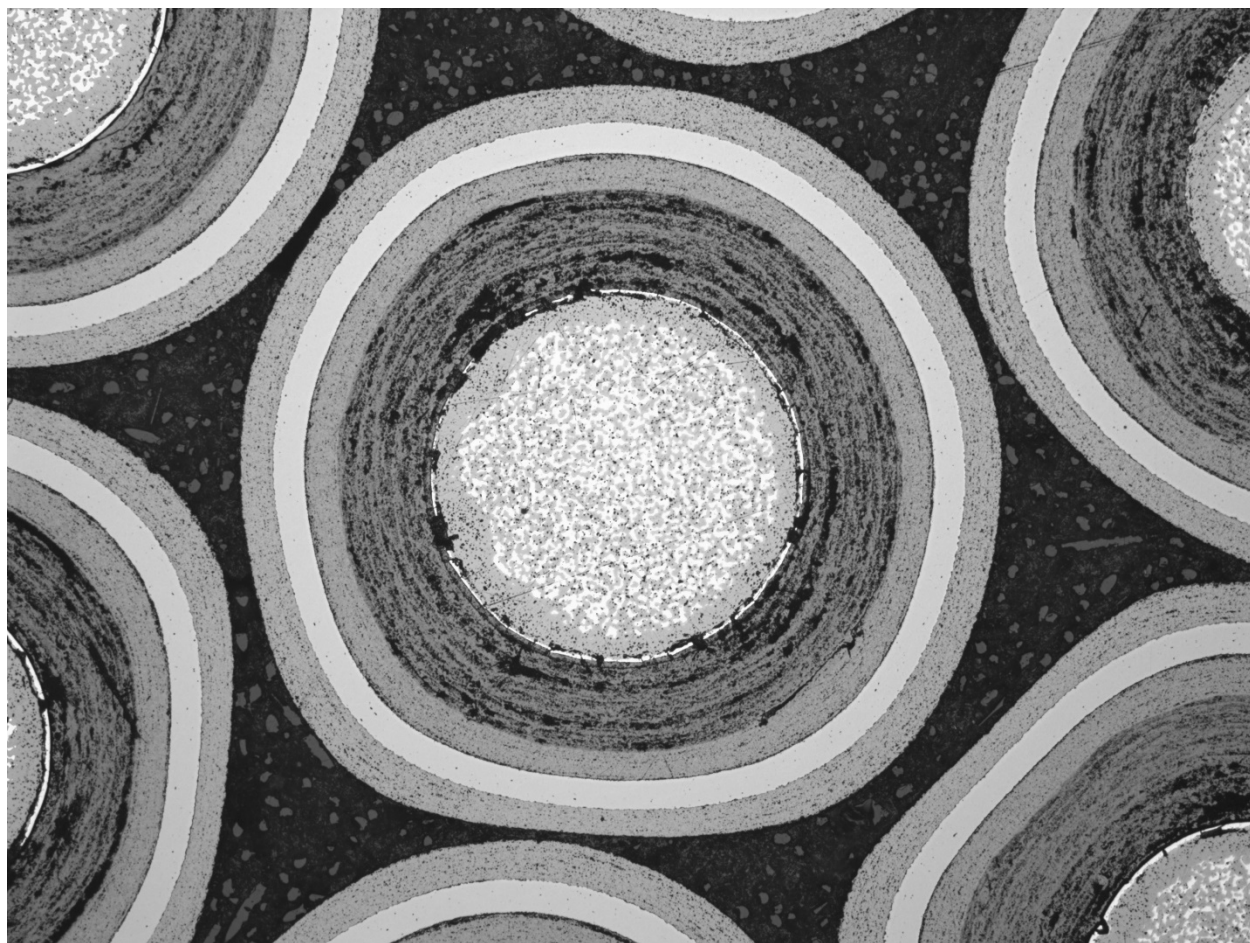


P16082301N068

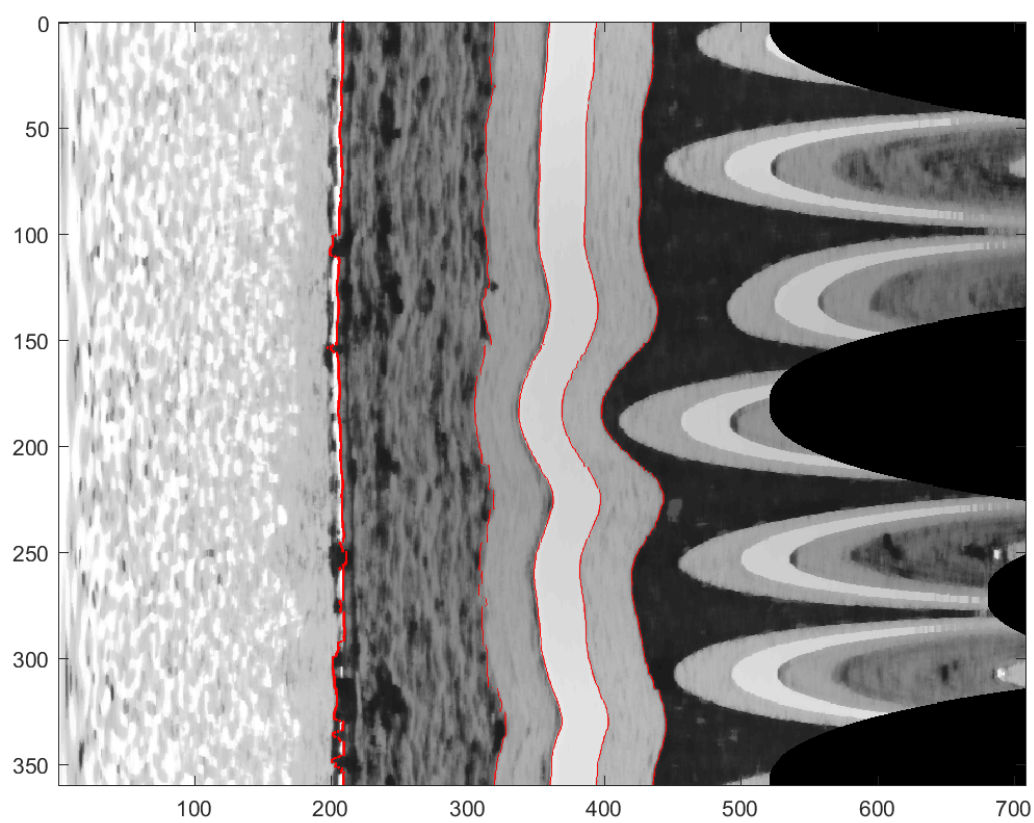




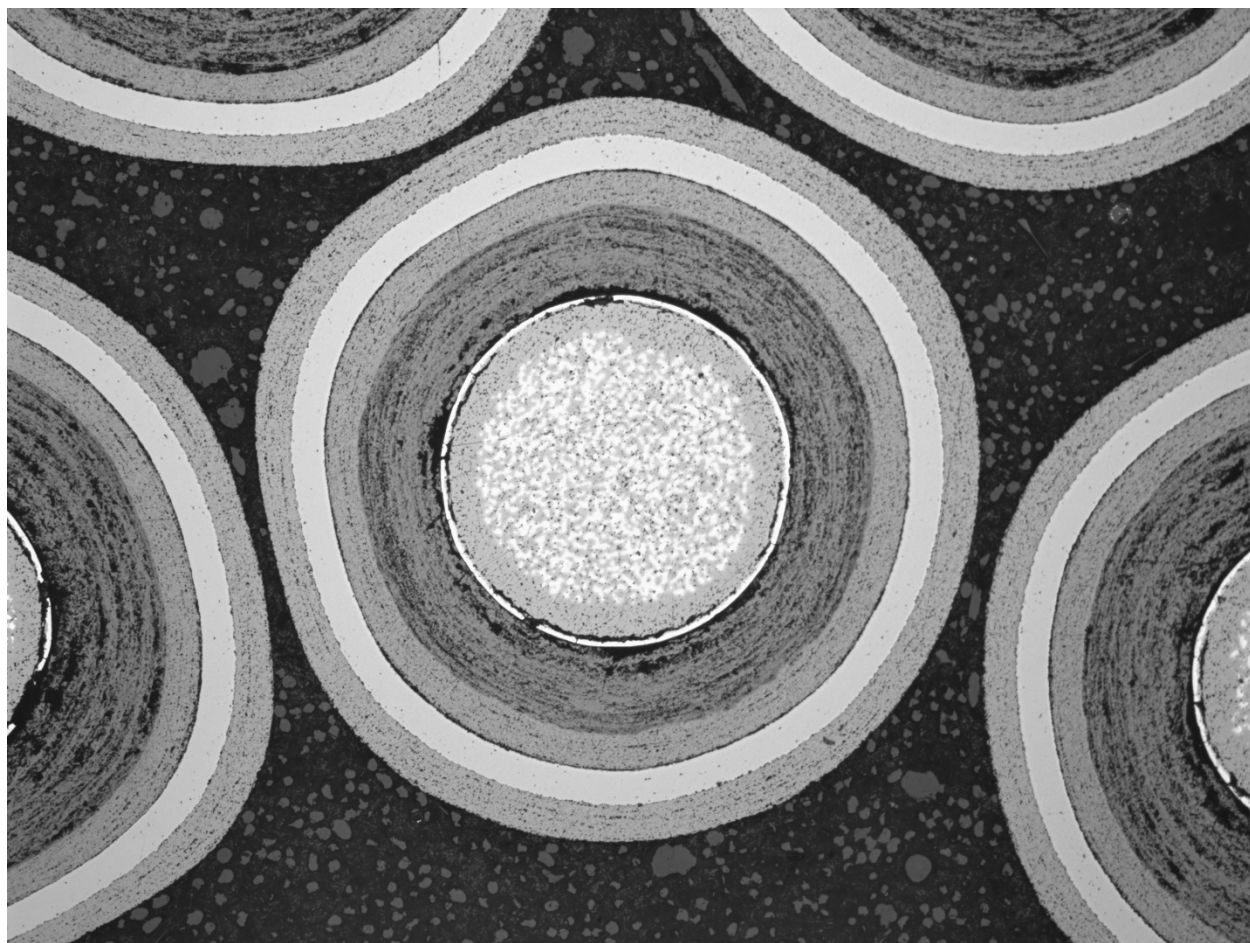
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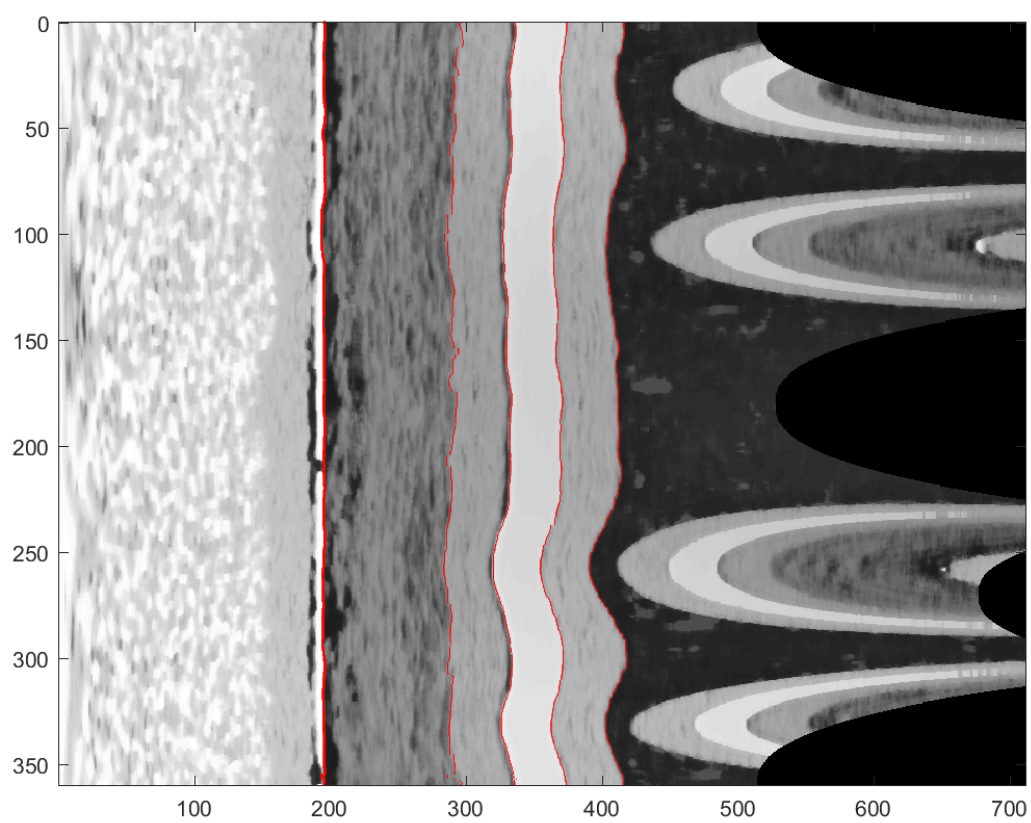
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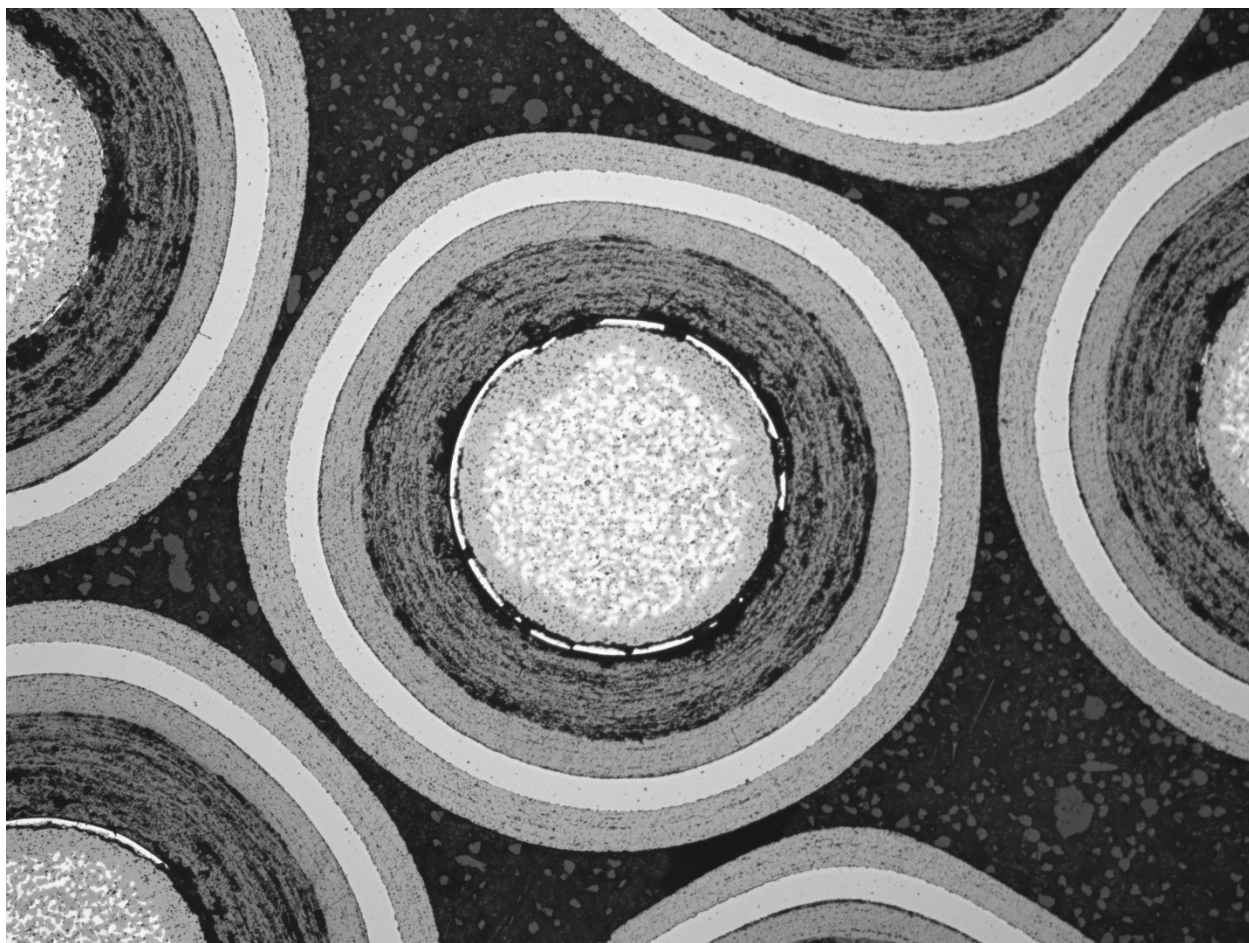
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P16082301N070

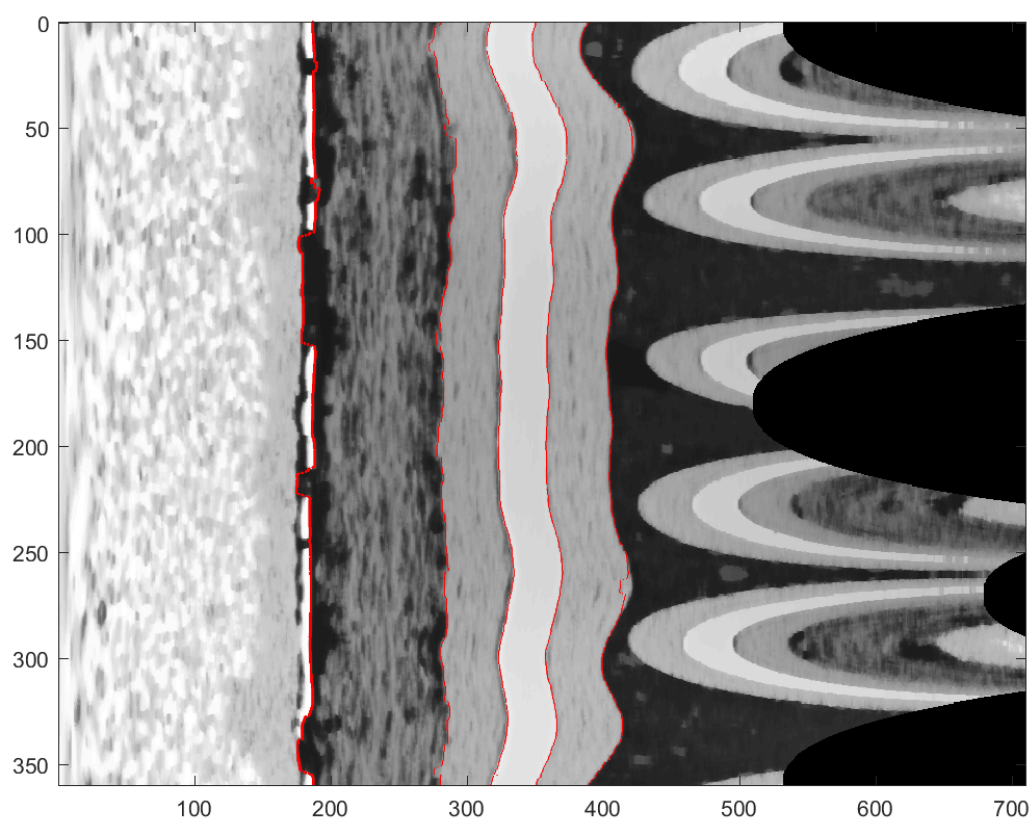


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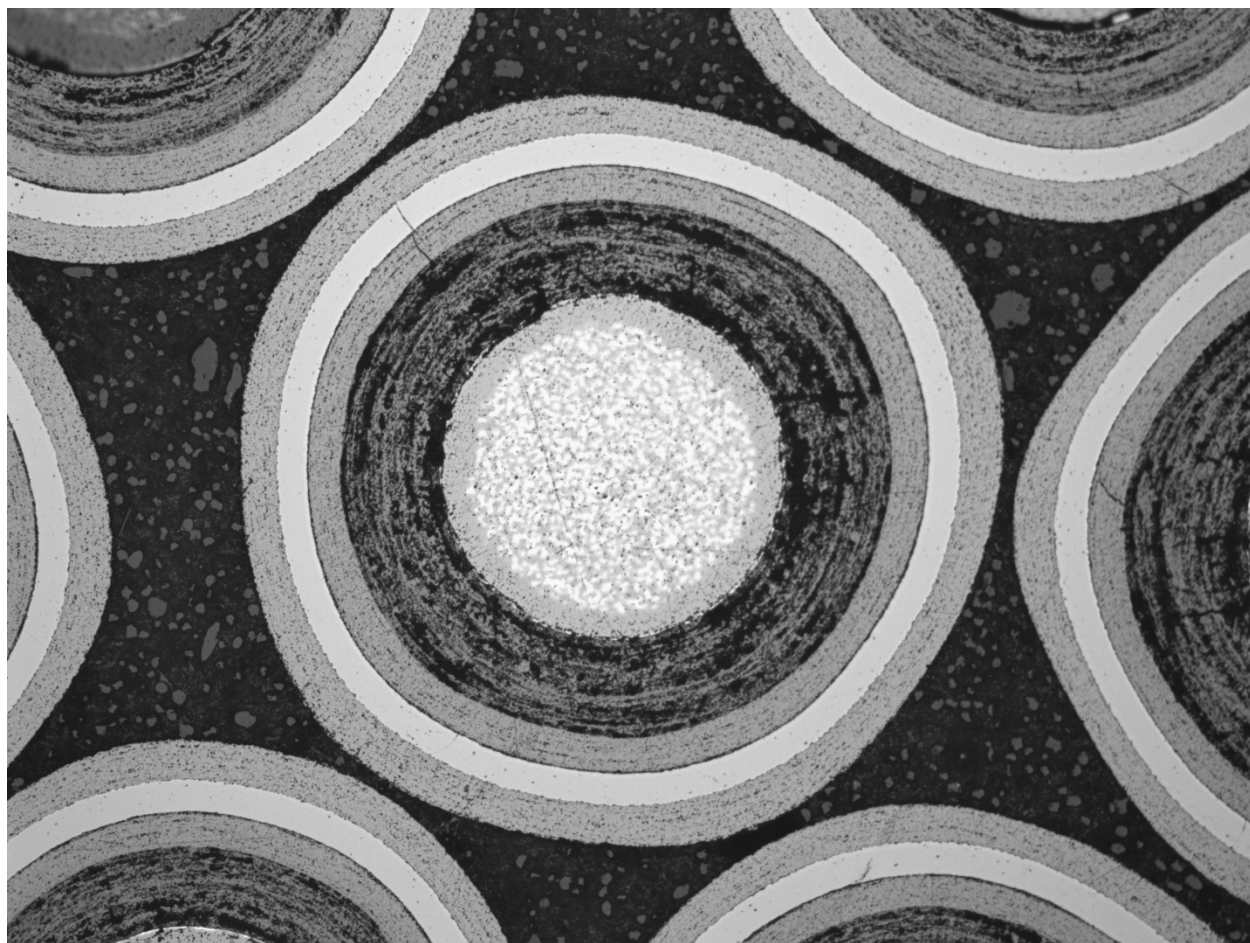
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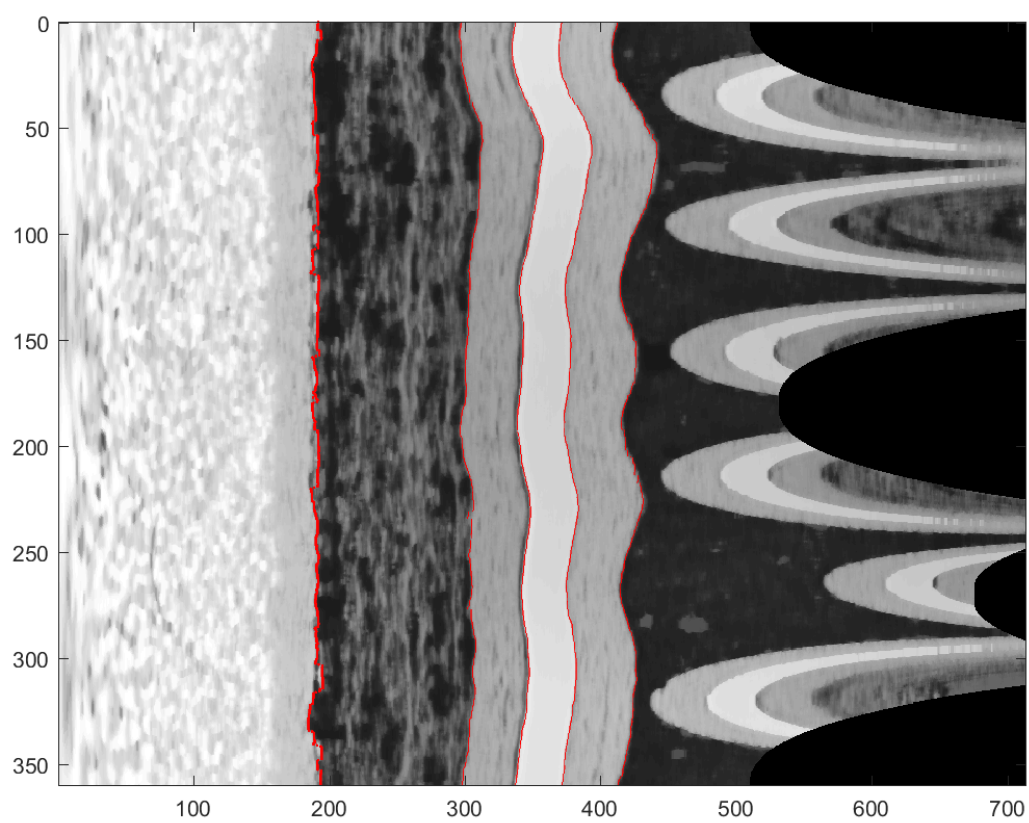


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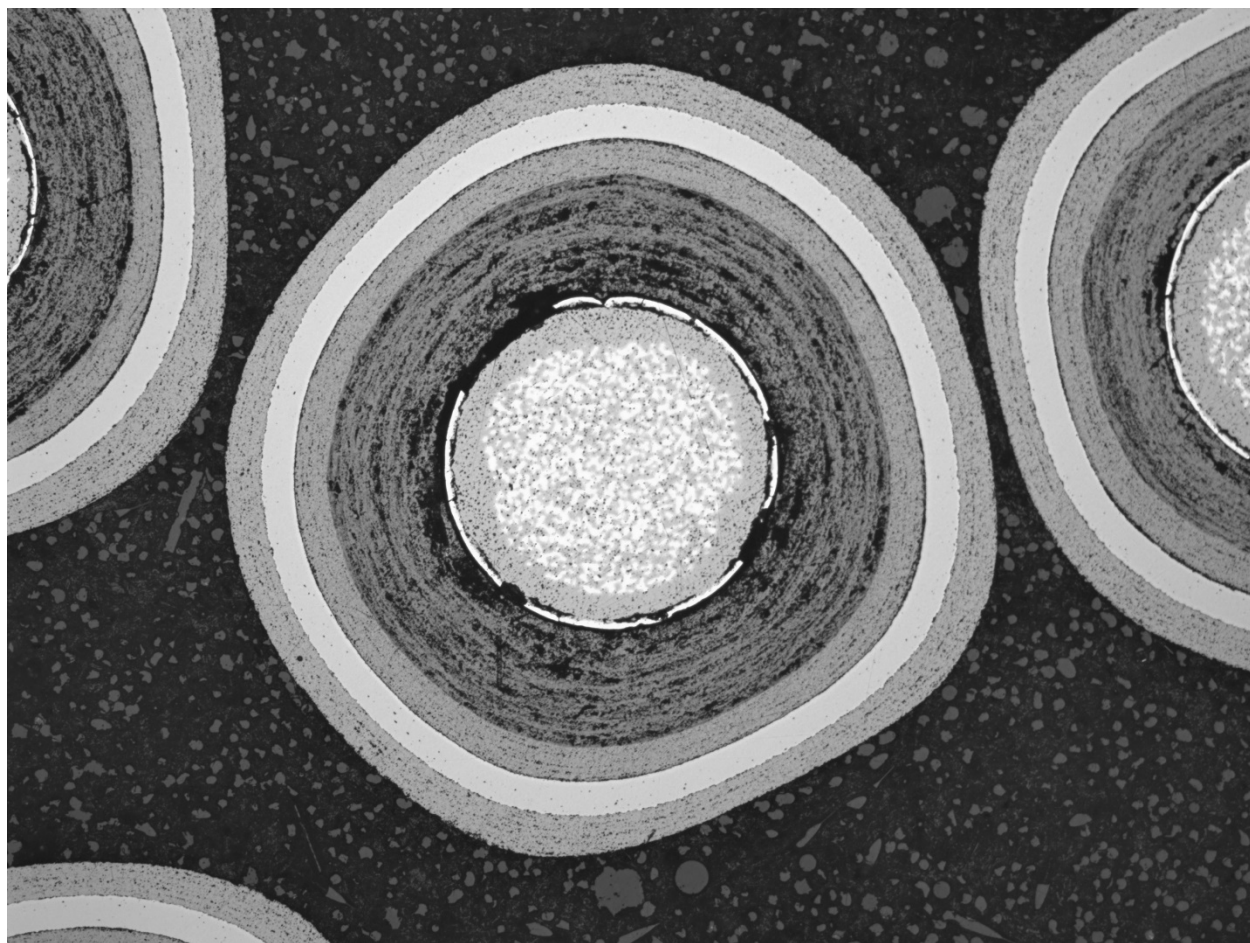




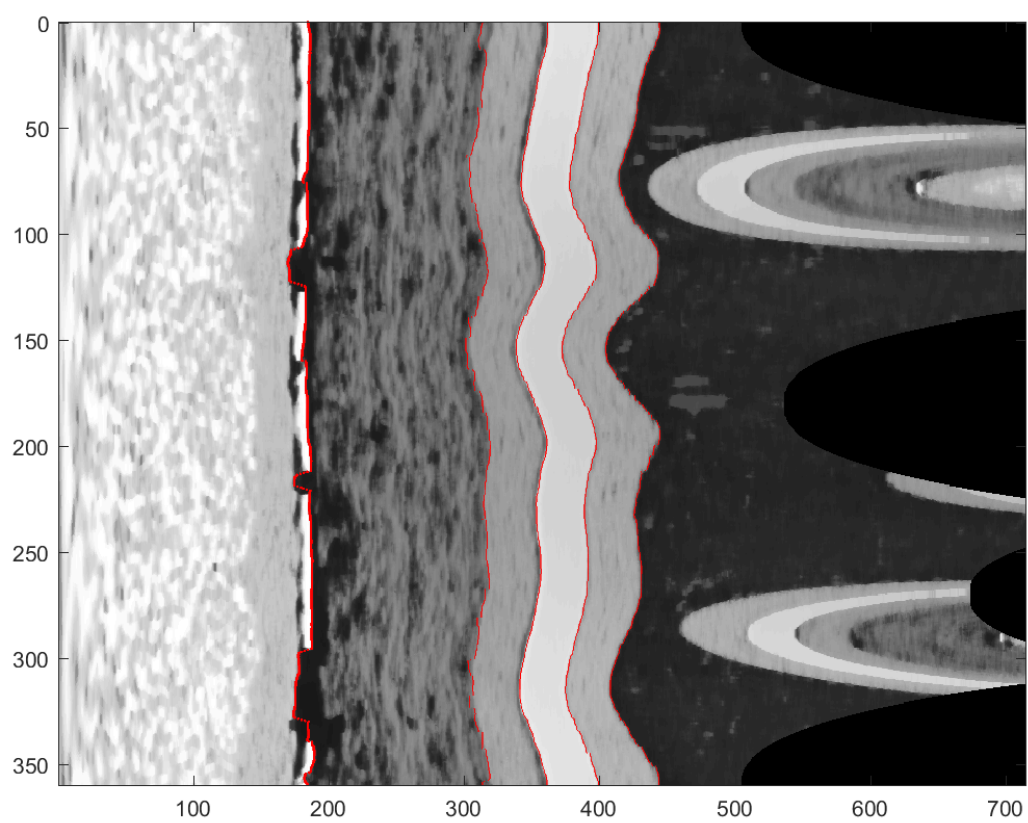
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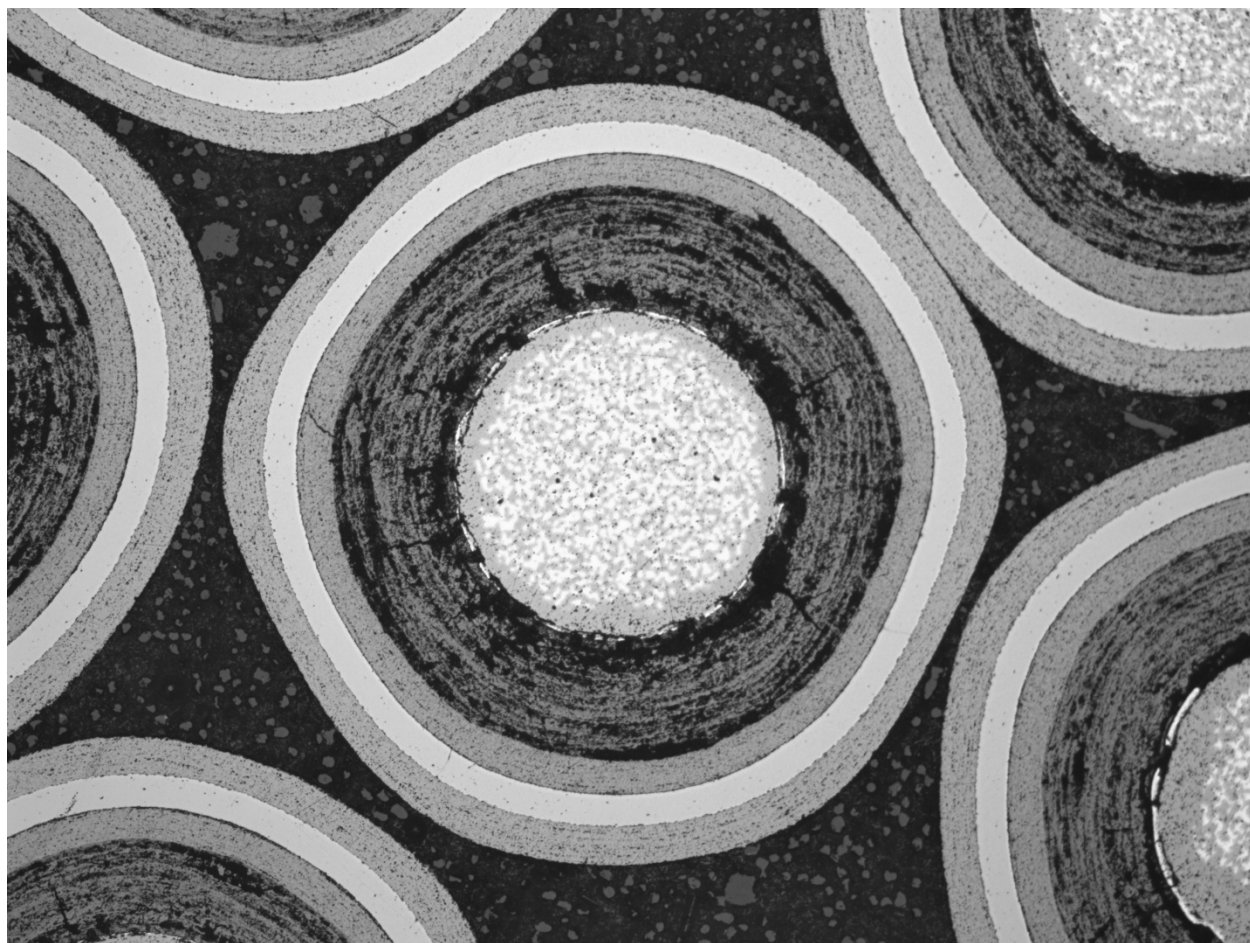
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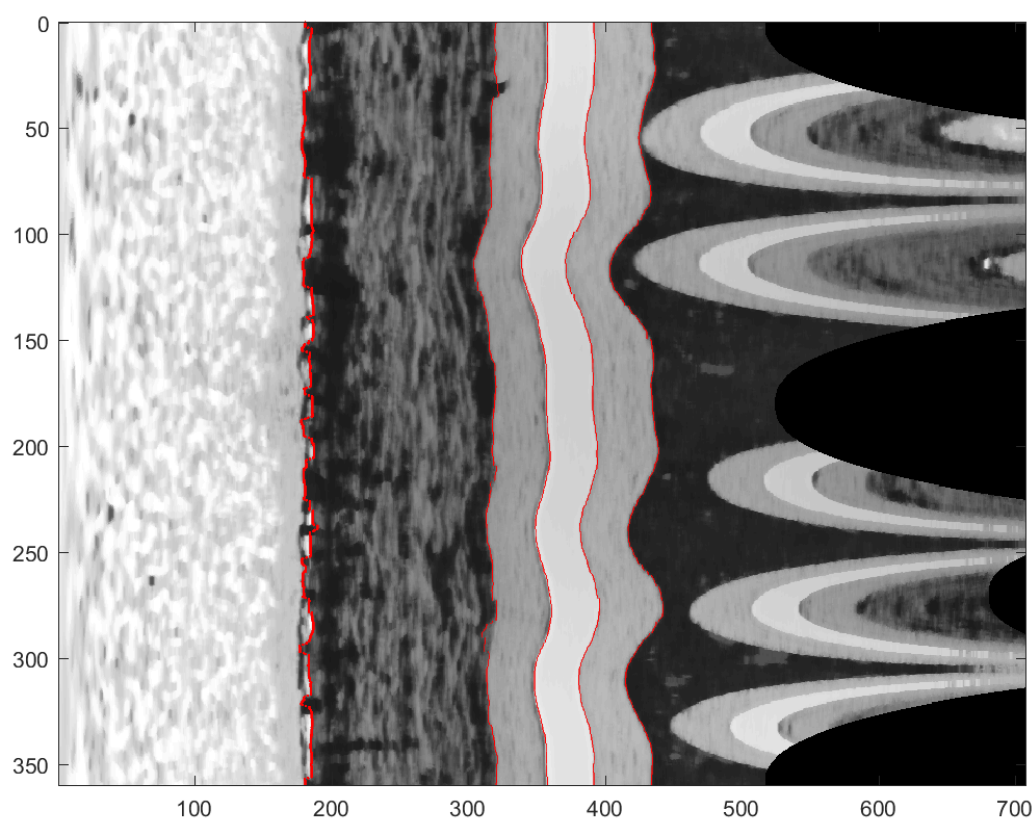
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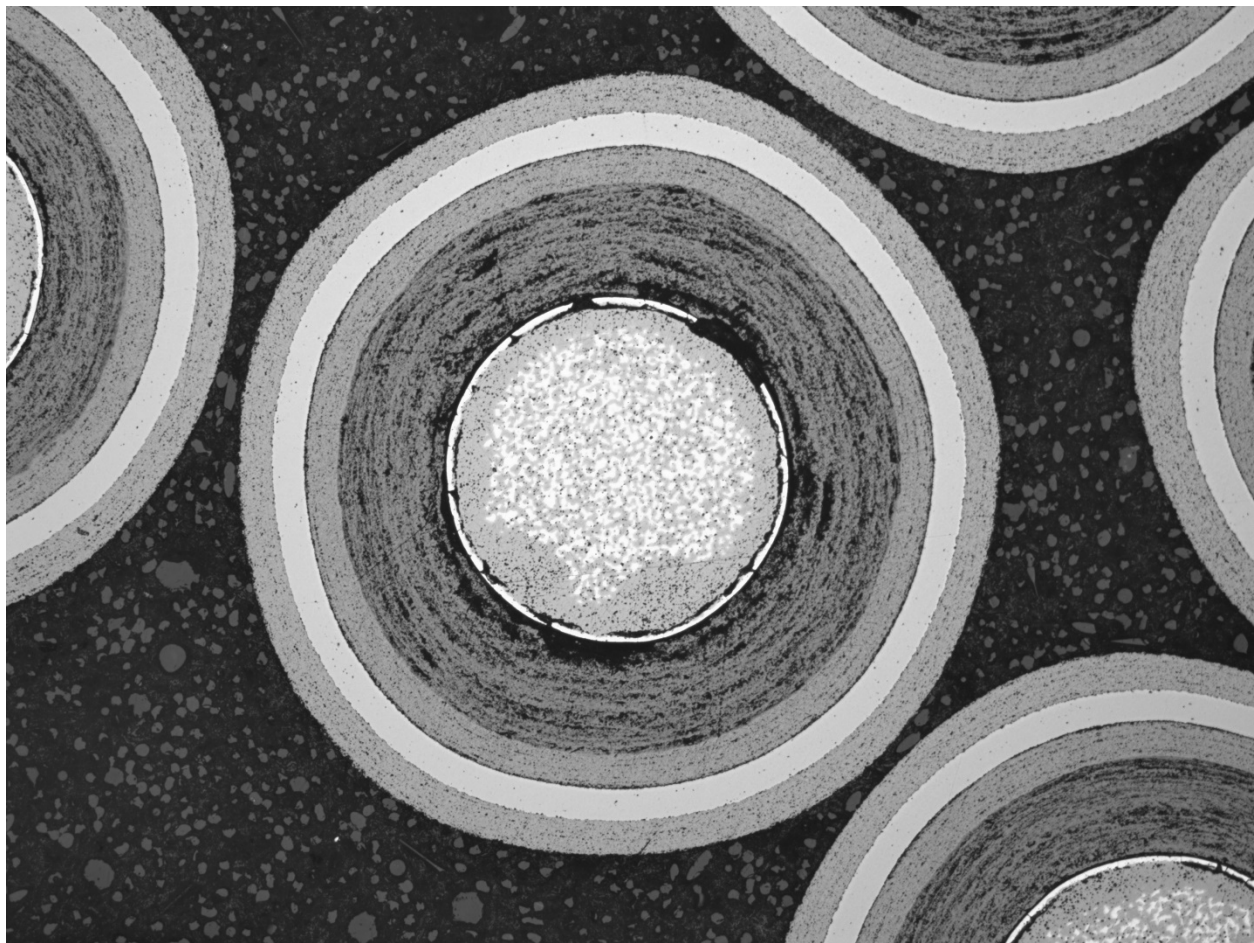


P16082301N075



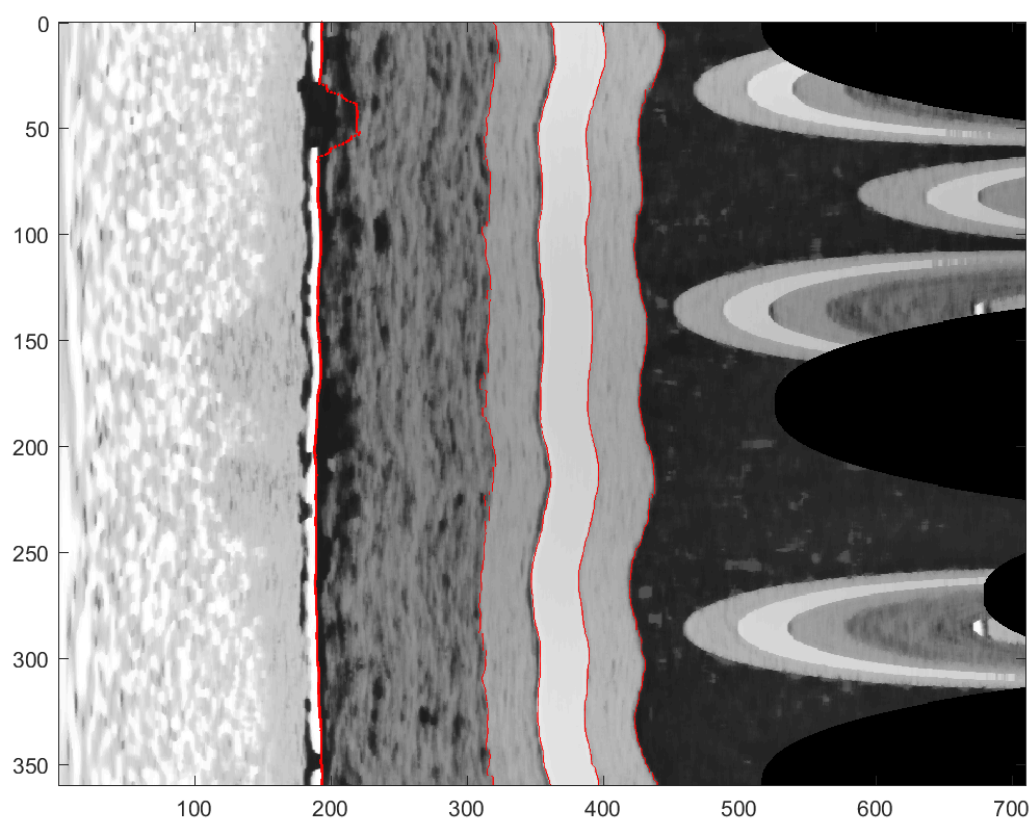
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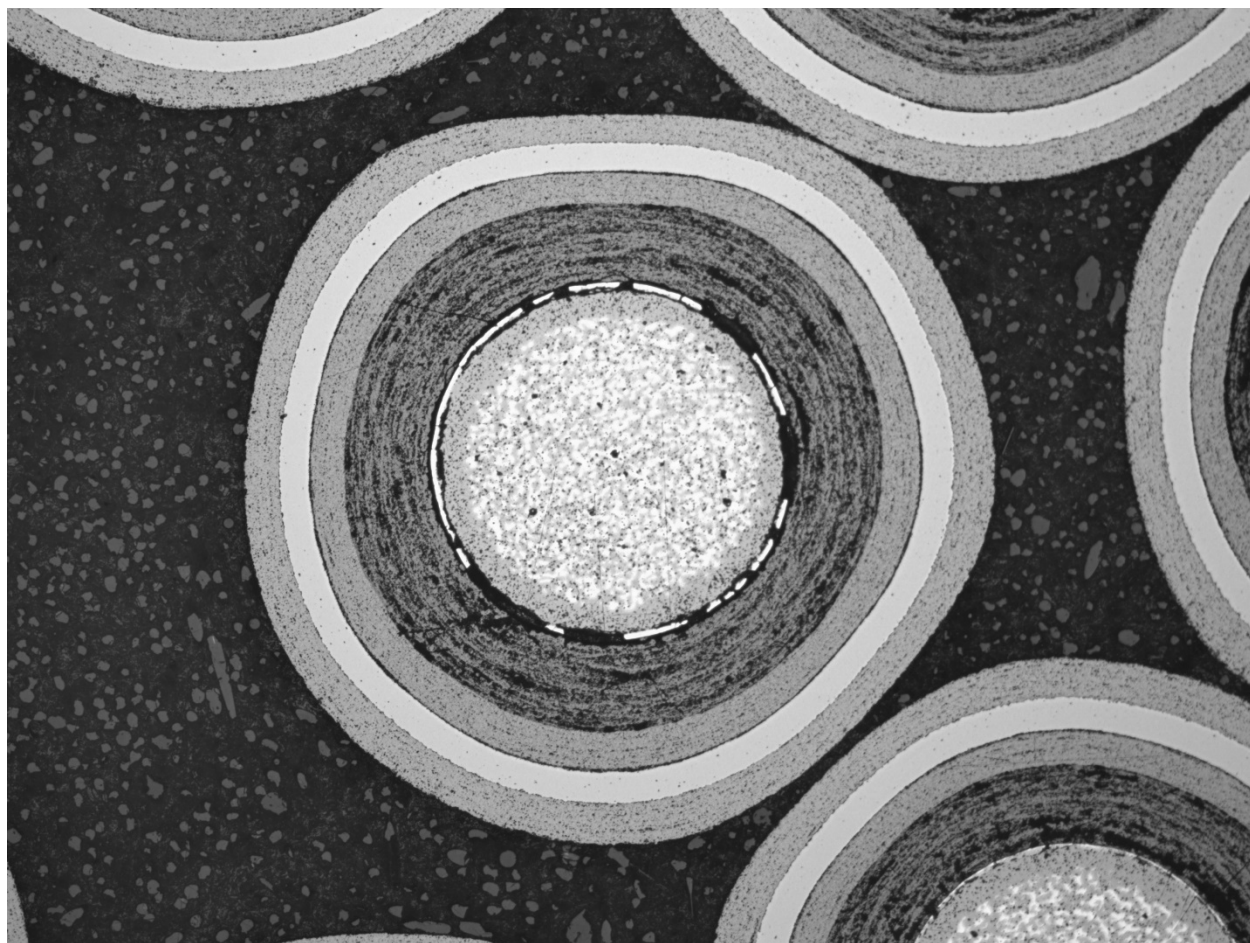


P16082301N076

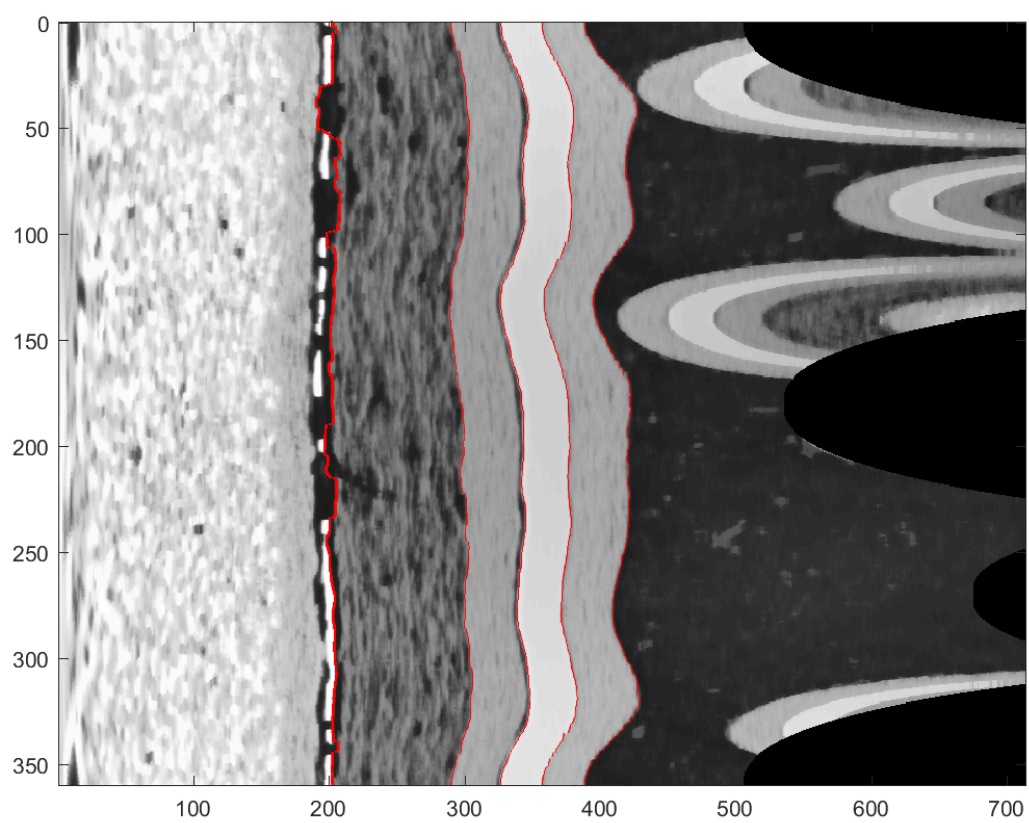




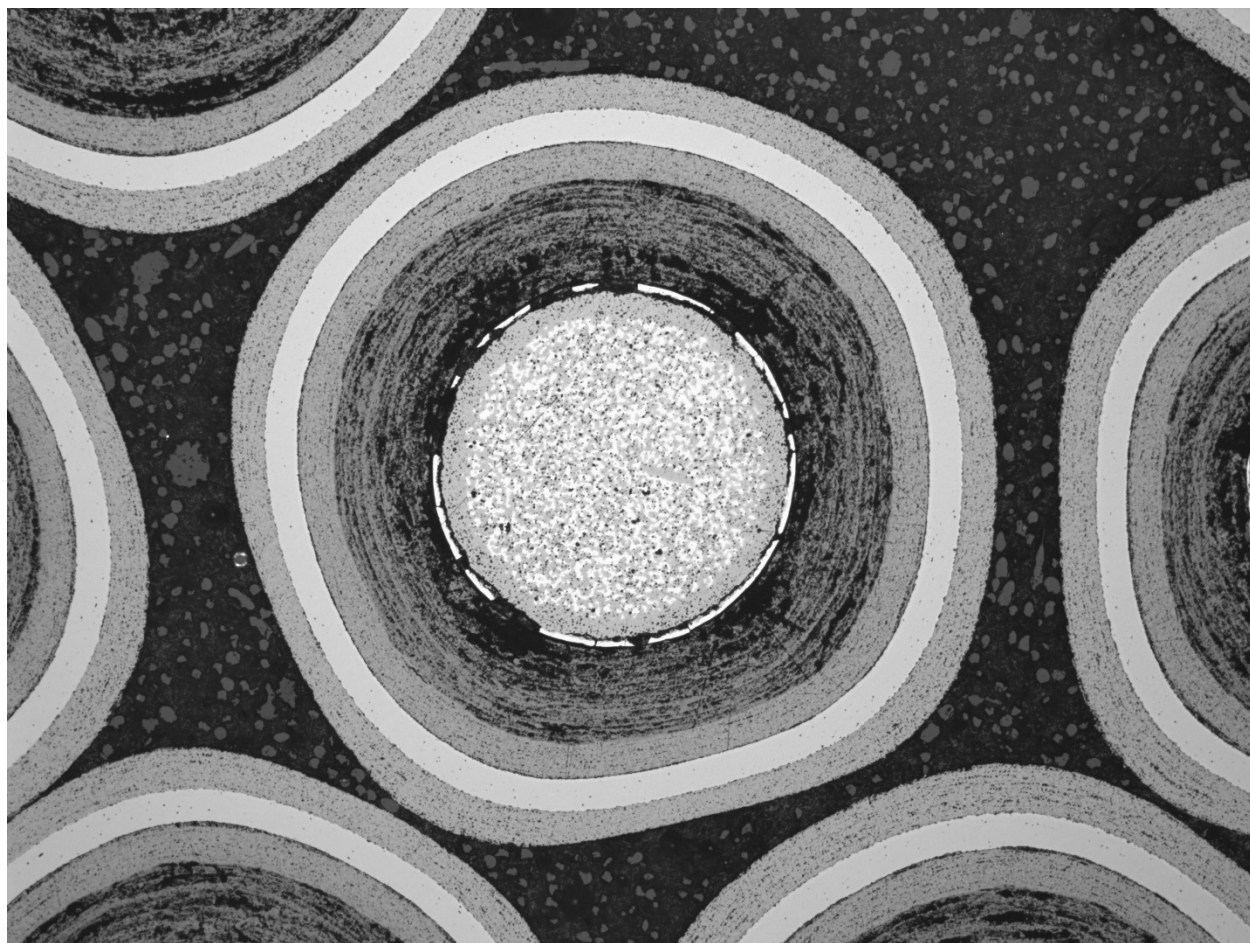
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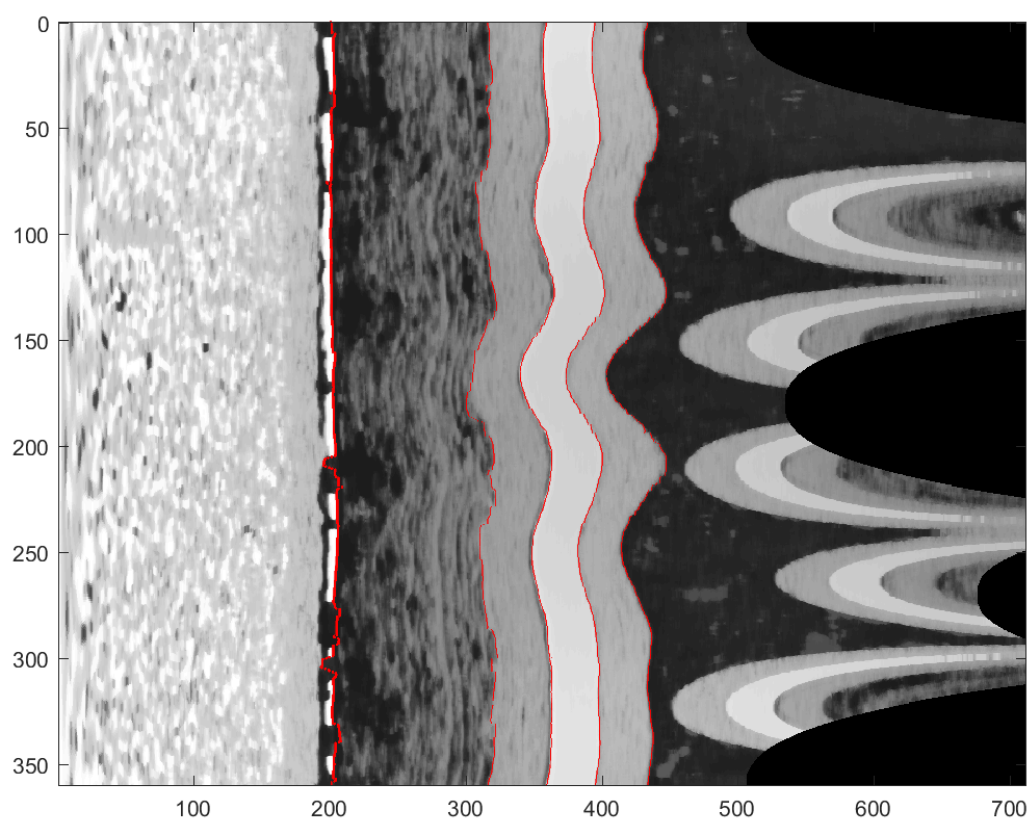
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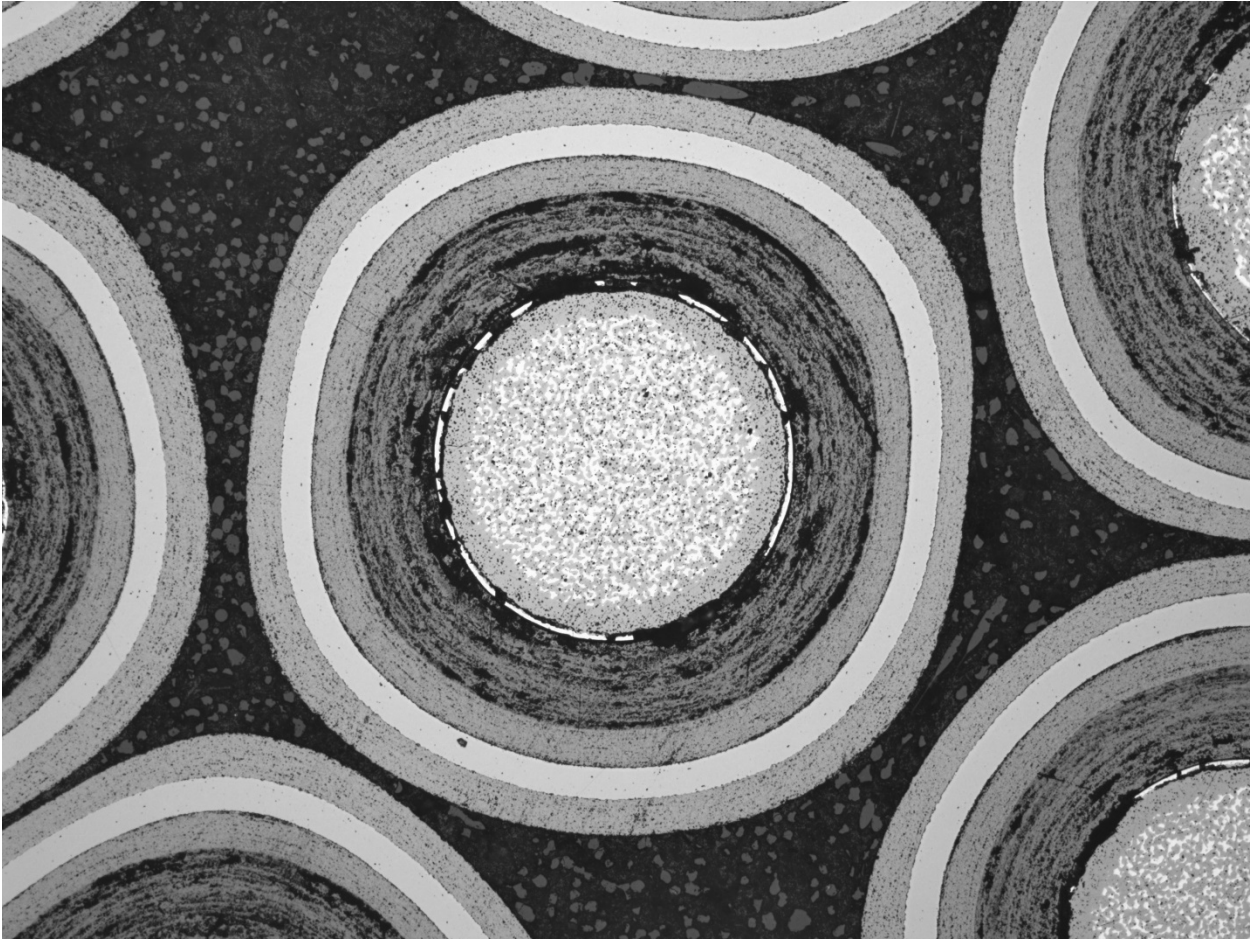
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P16082301N078

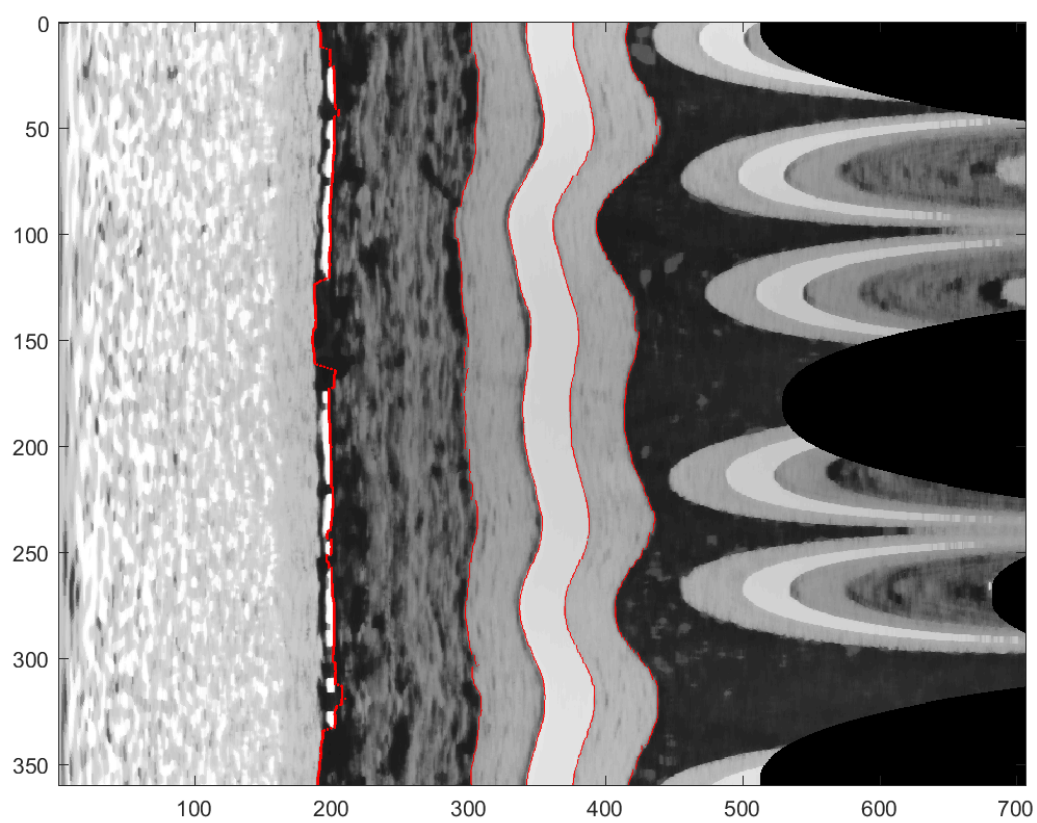


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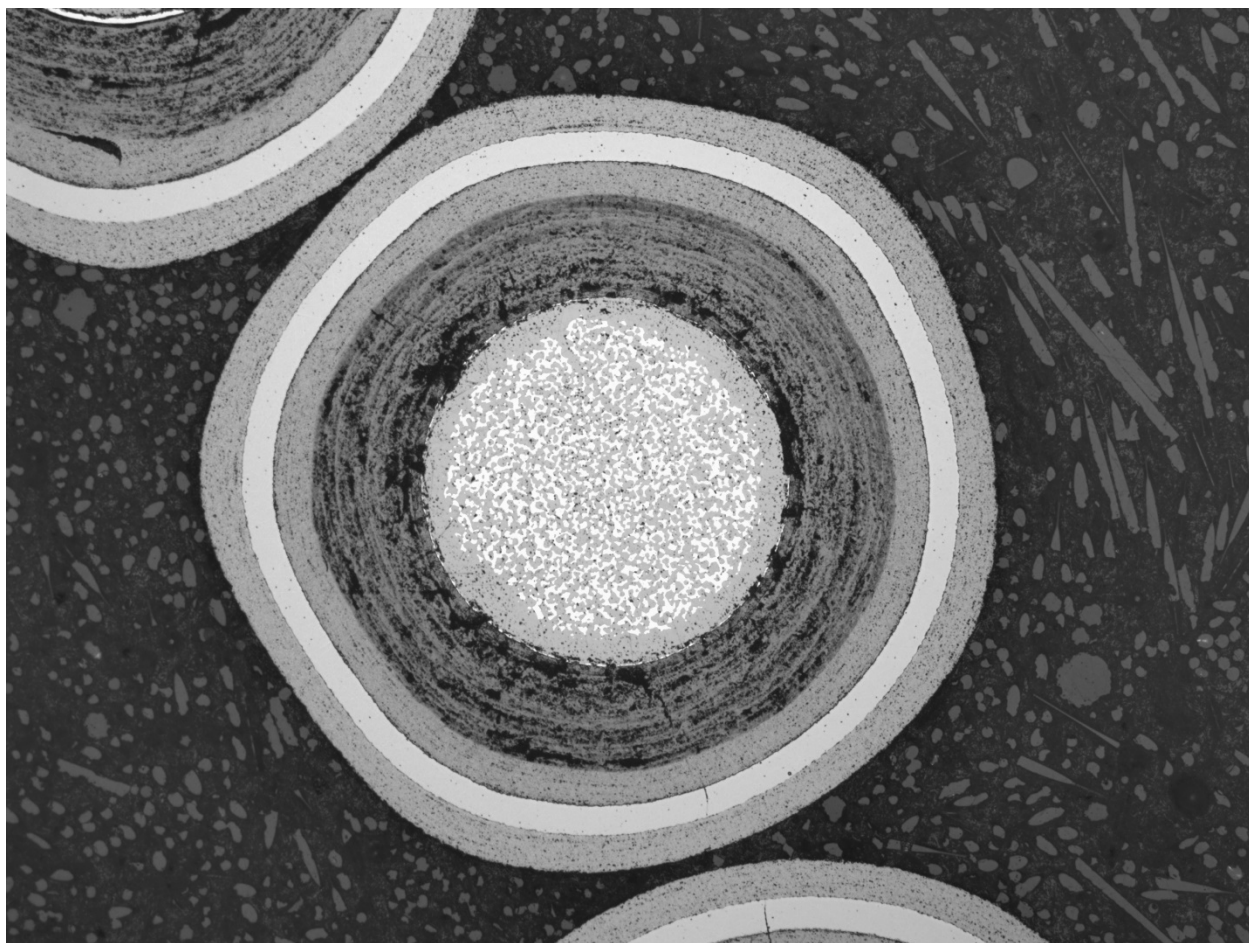
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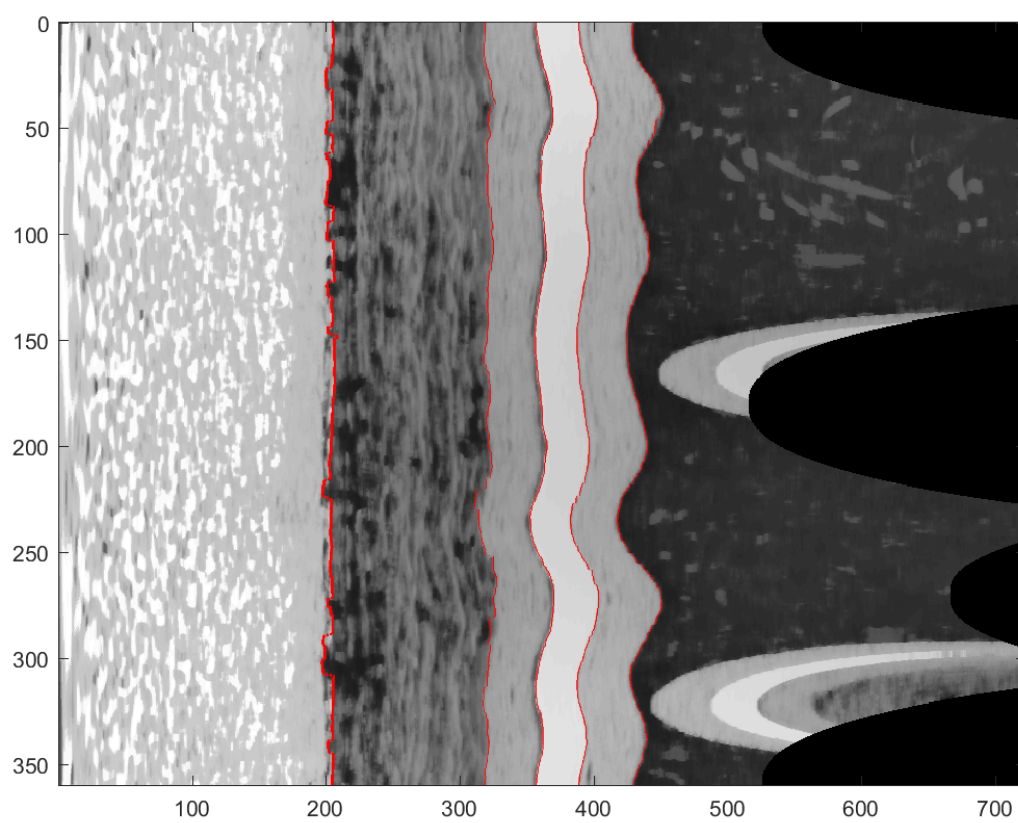


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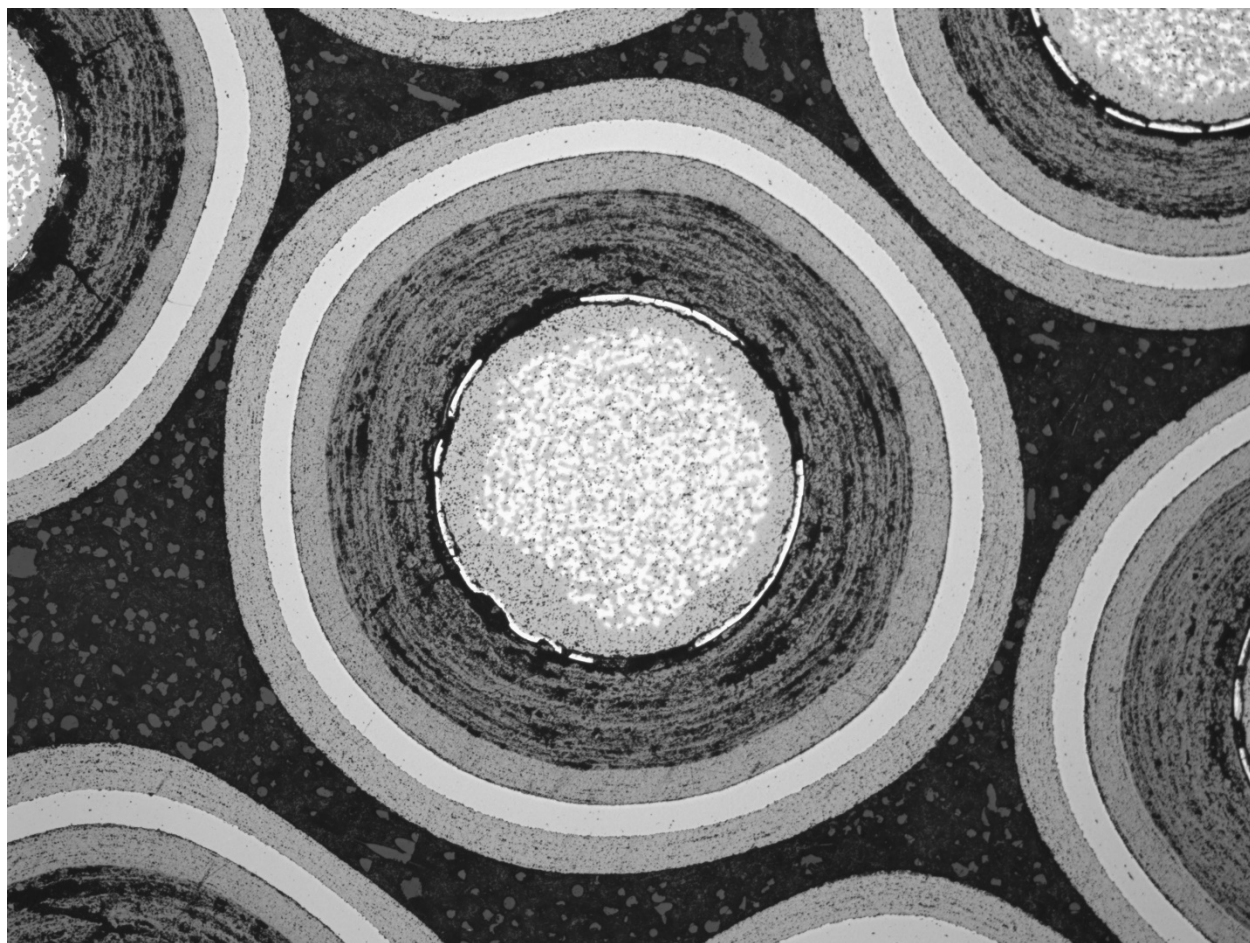




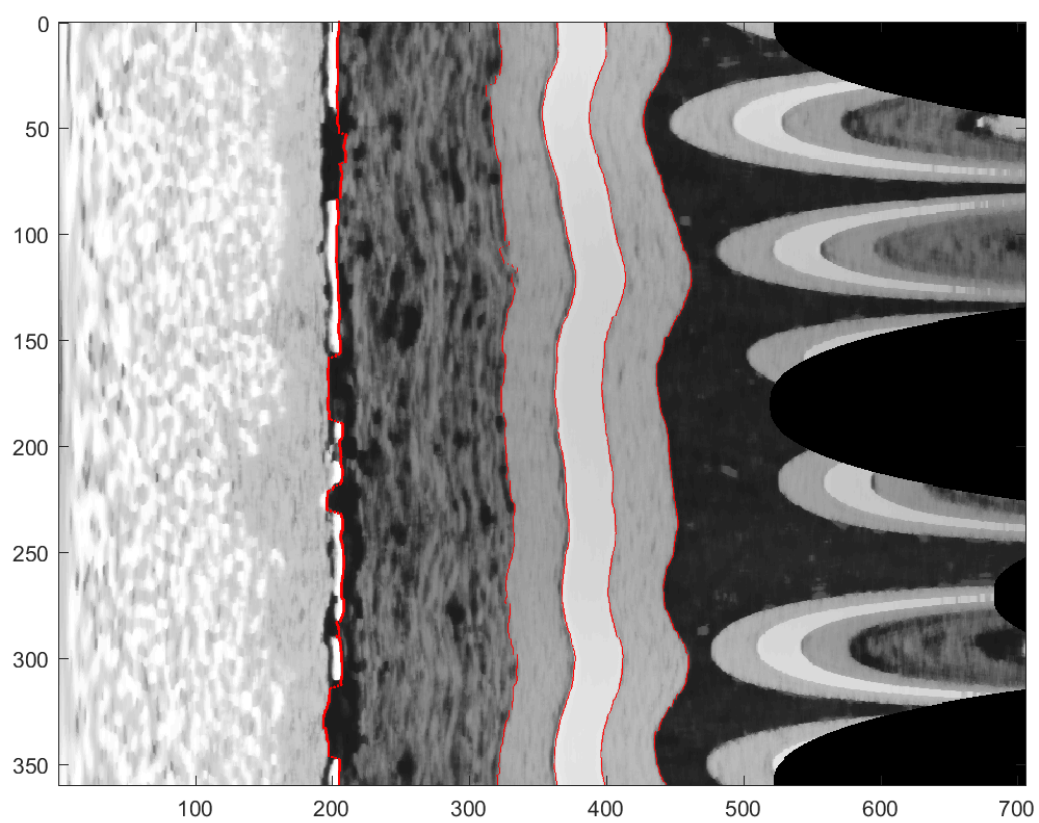
P16082301N082



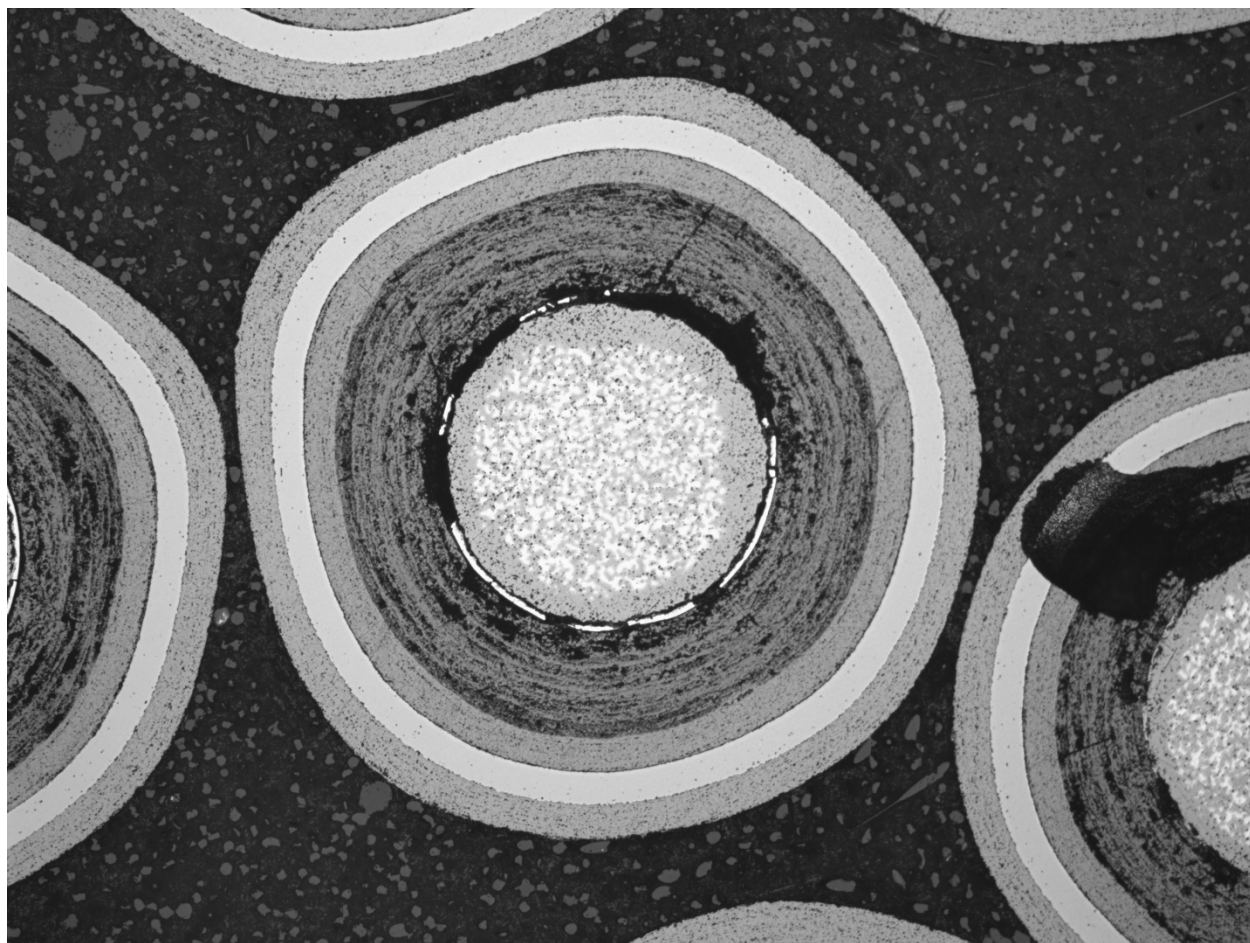
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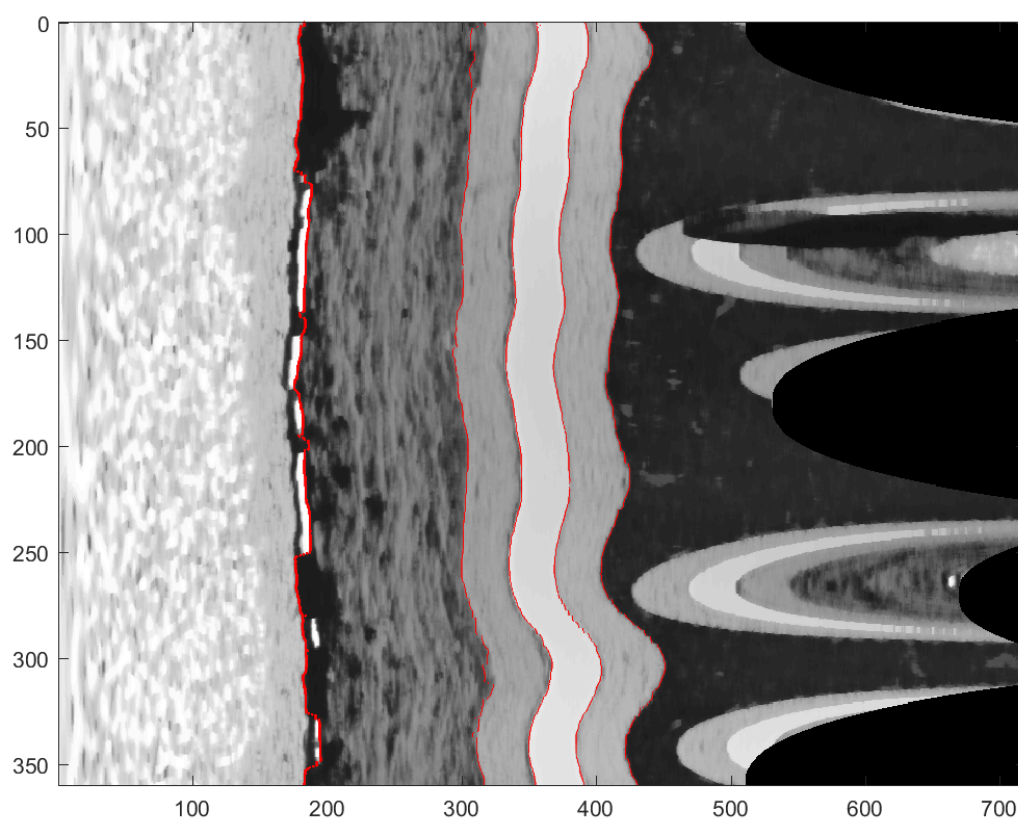
P16082301N084



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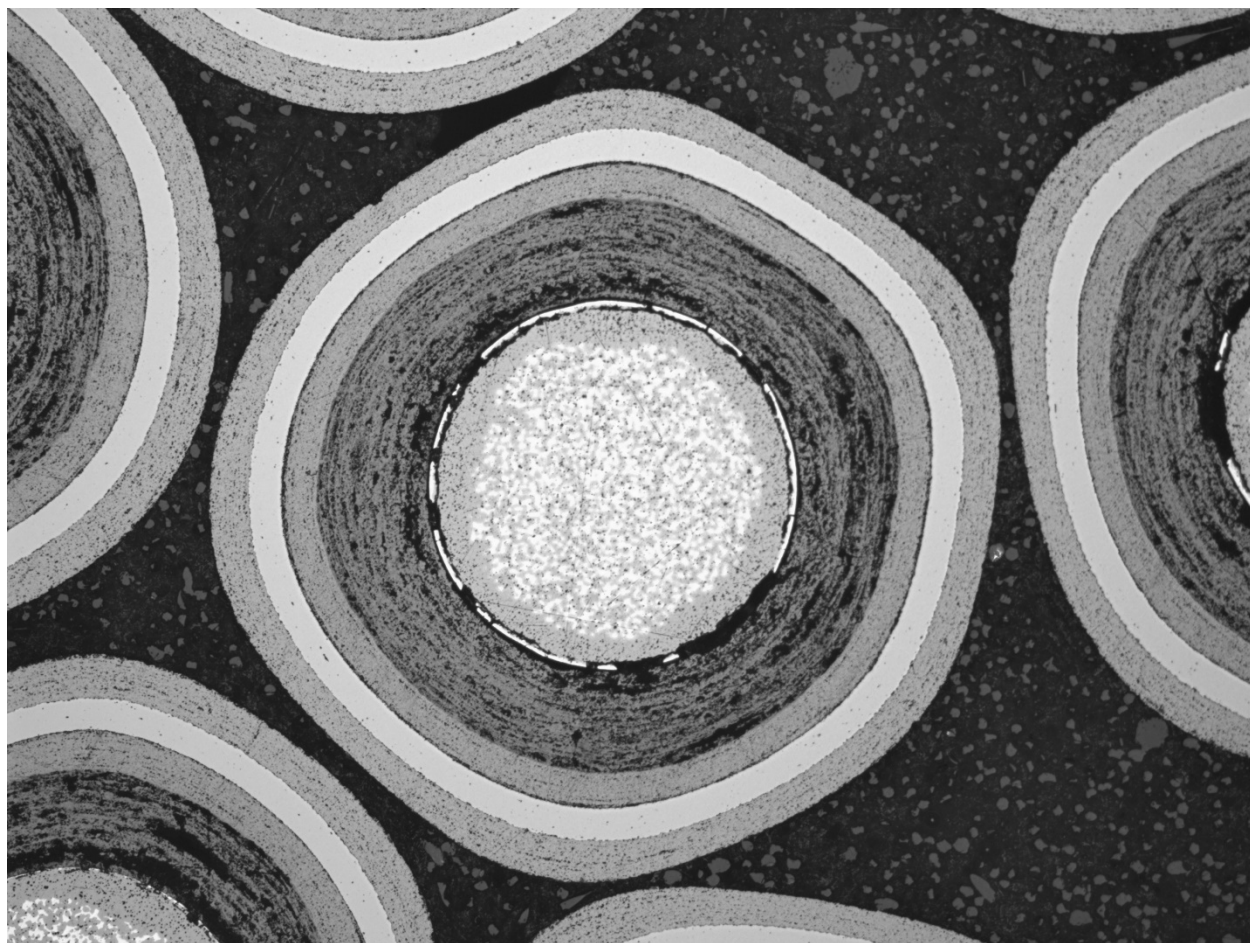


P16082301N085



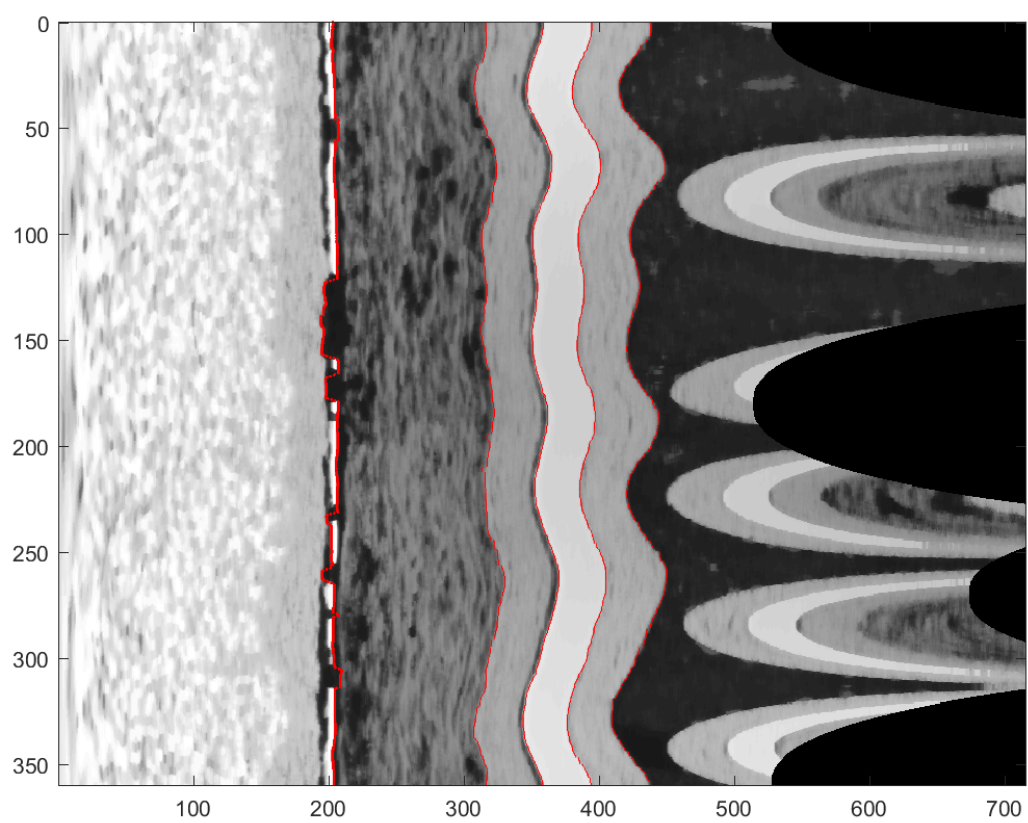
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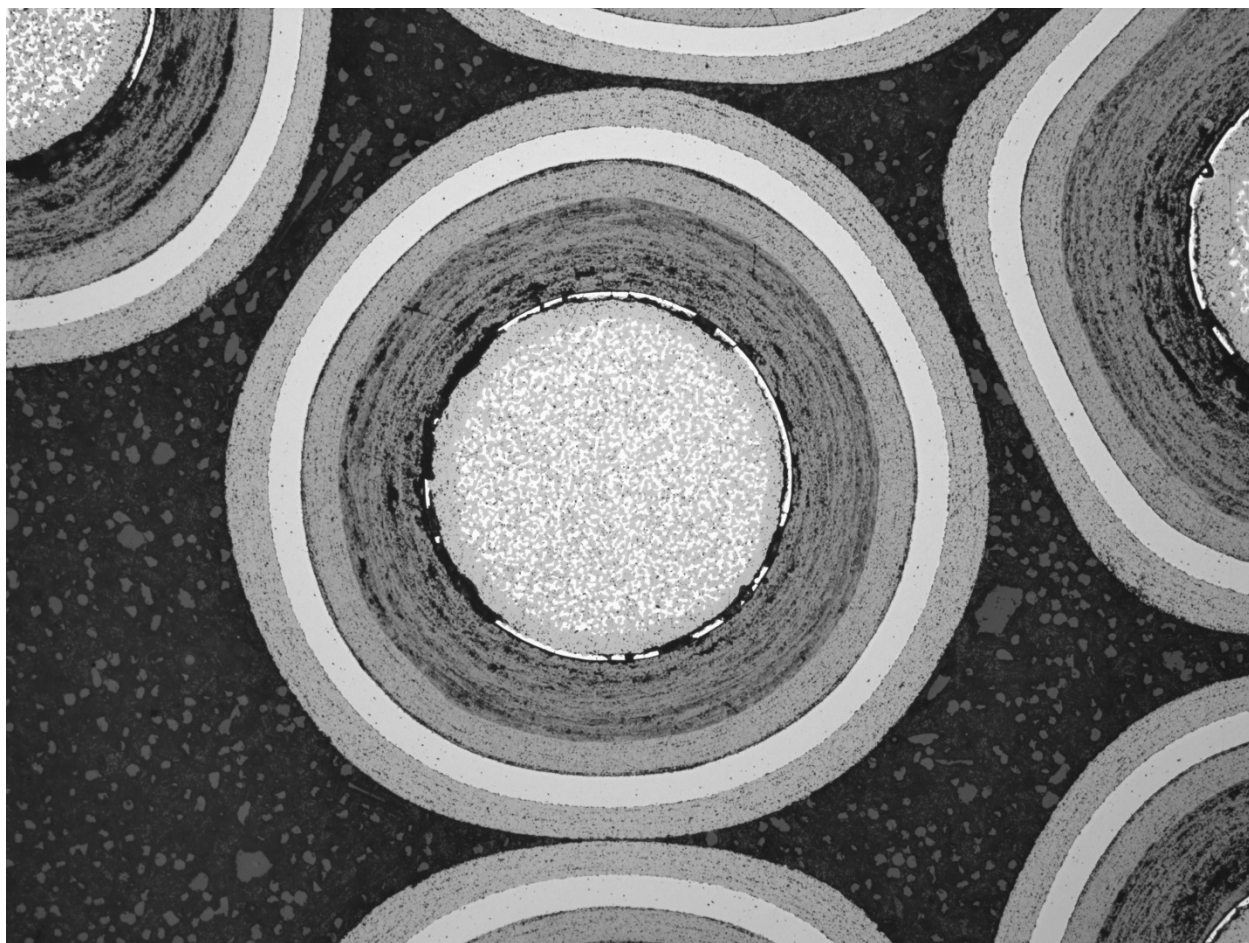


P16082301N086

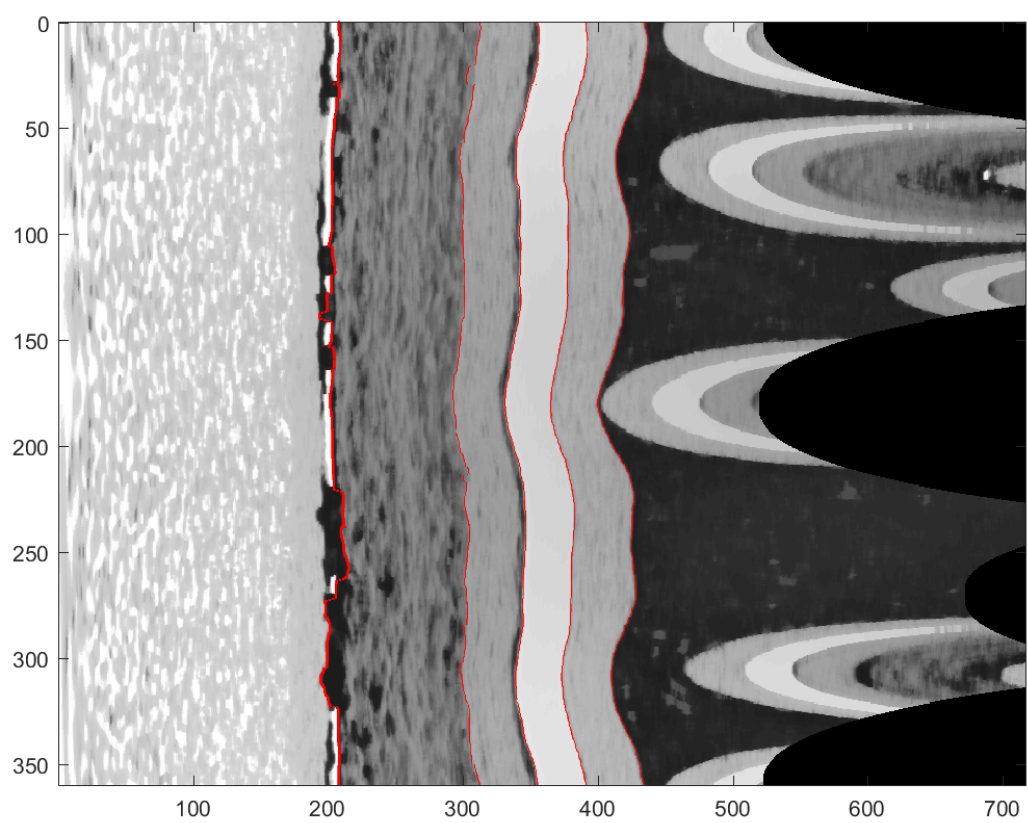




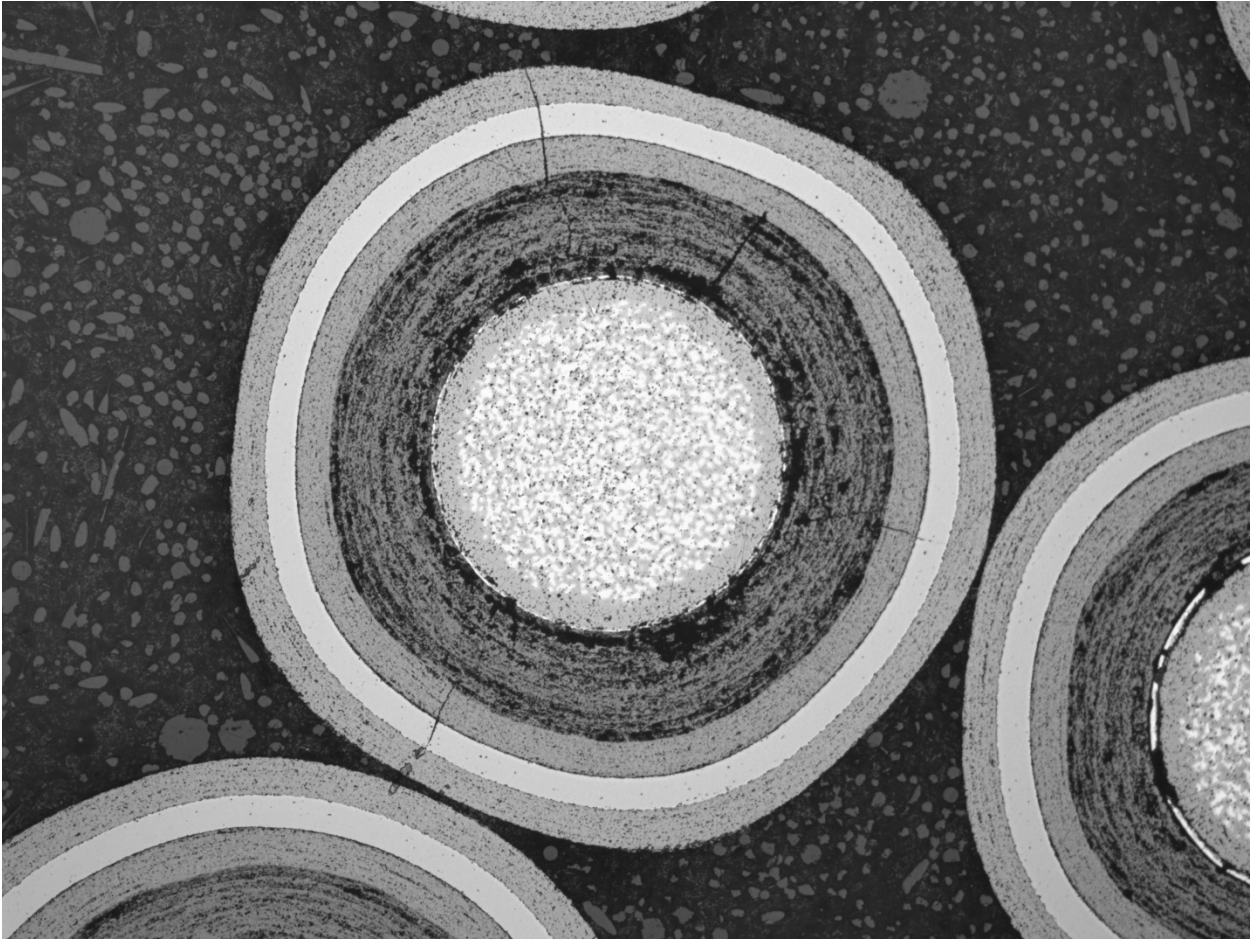
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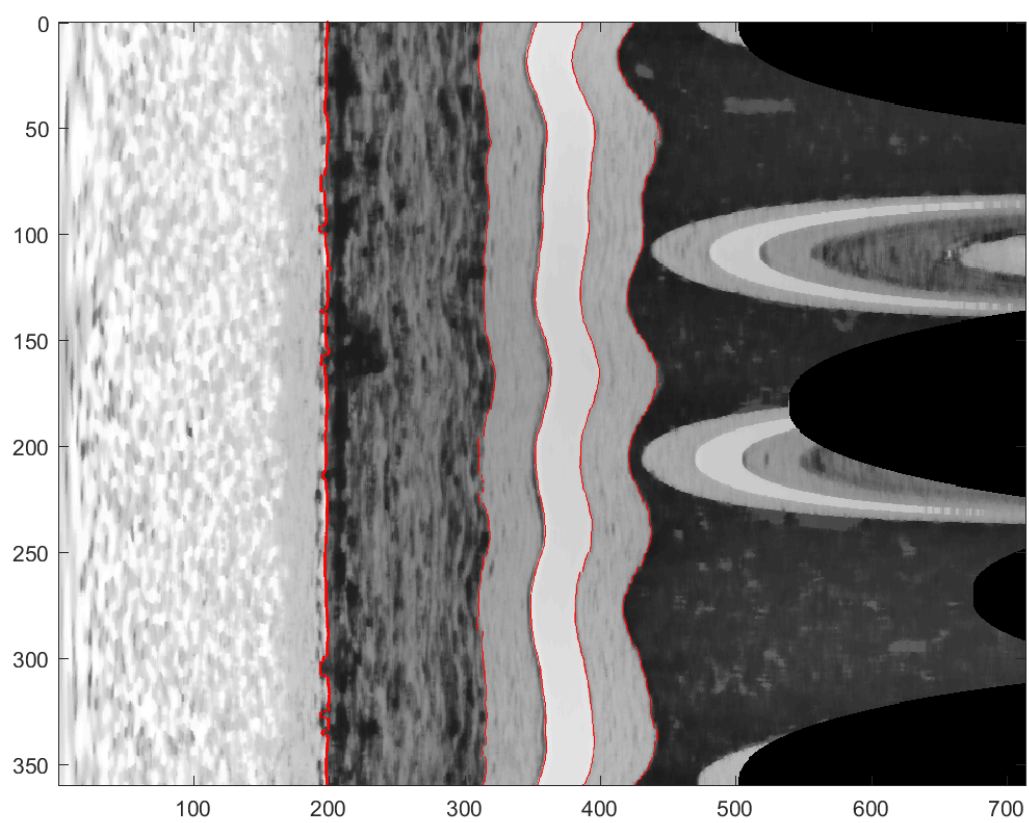
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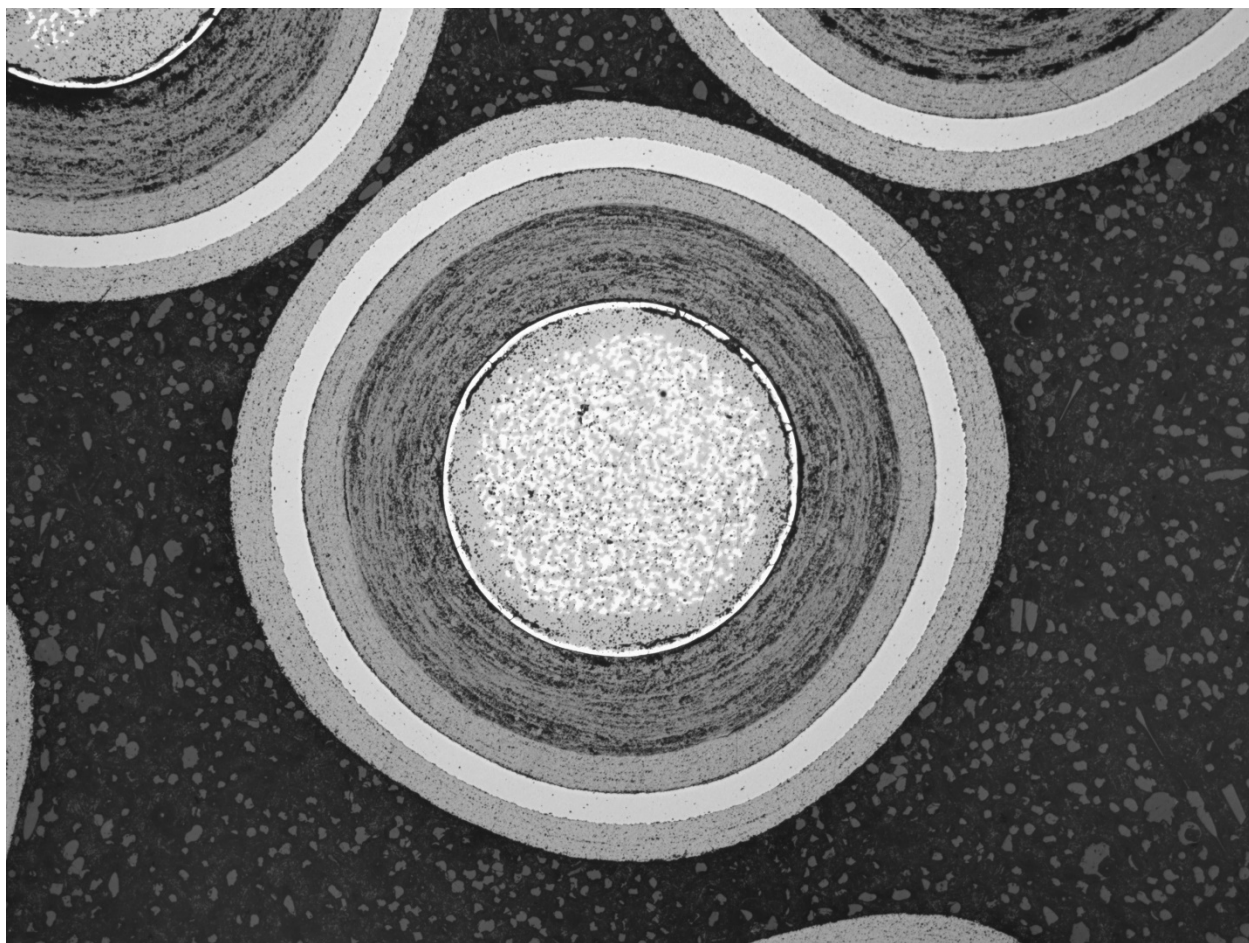
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P16082301N088

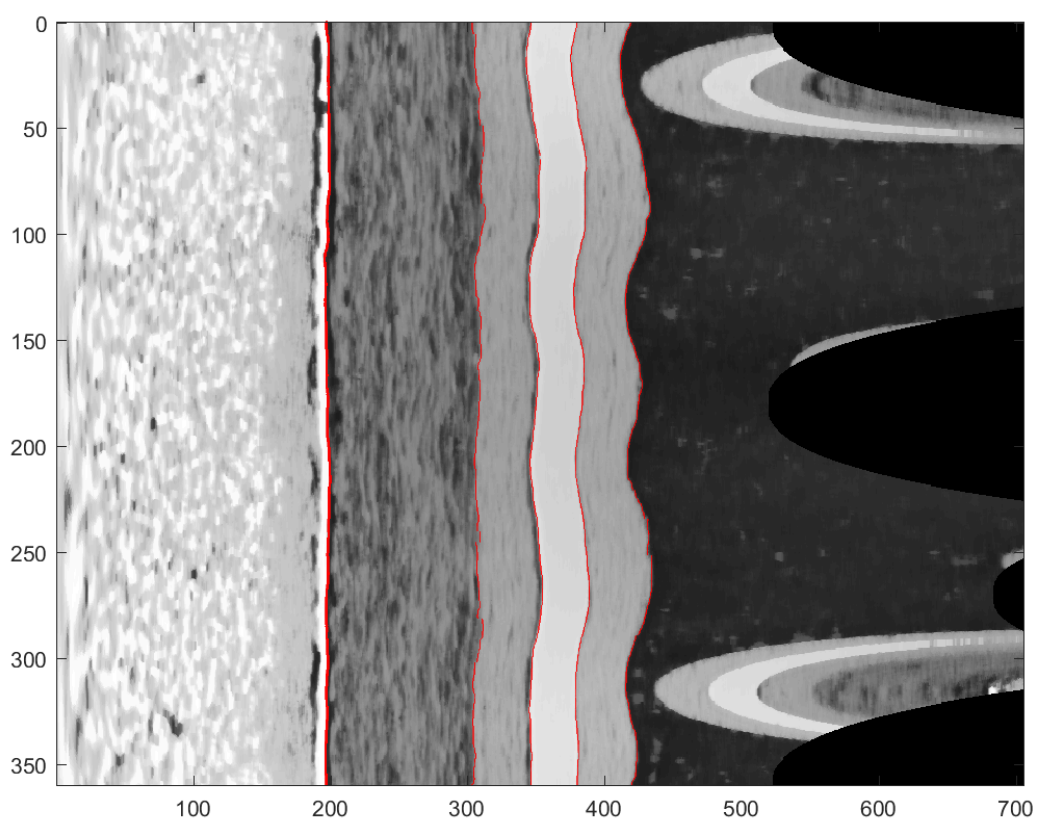


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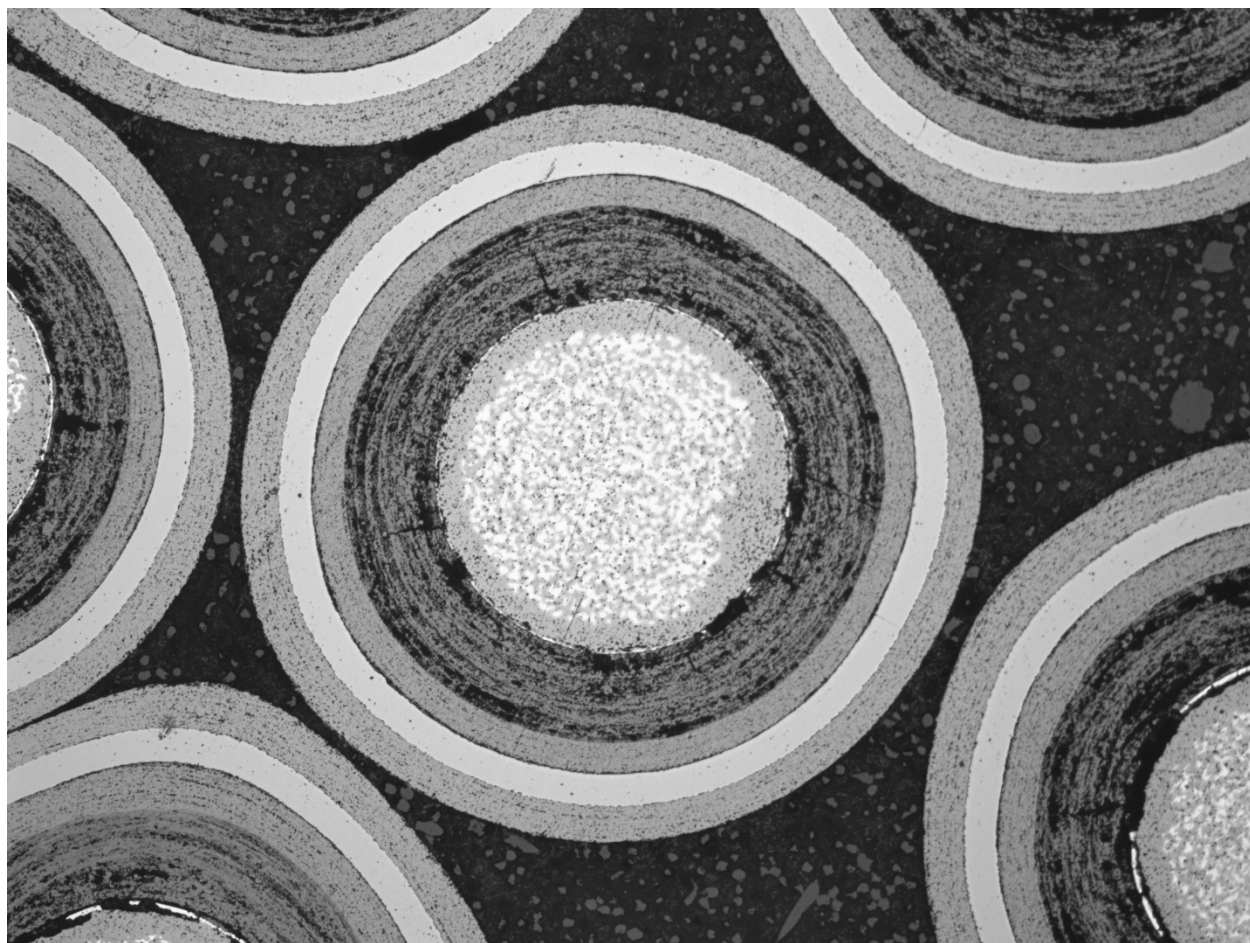
P16082301N090



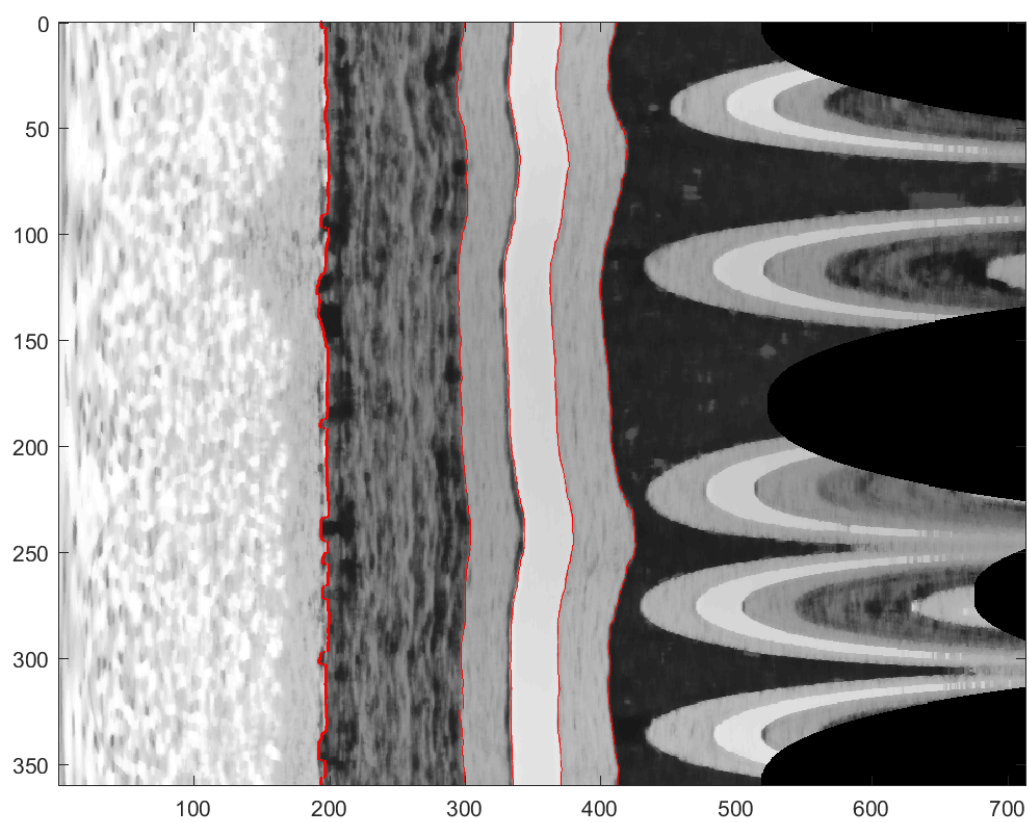


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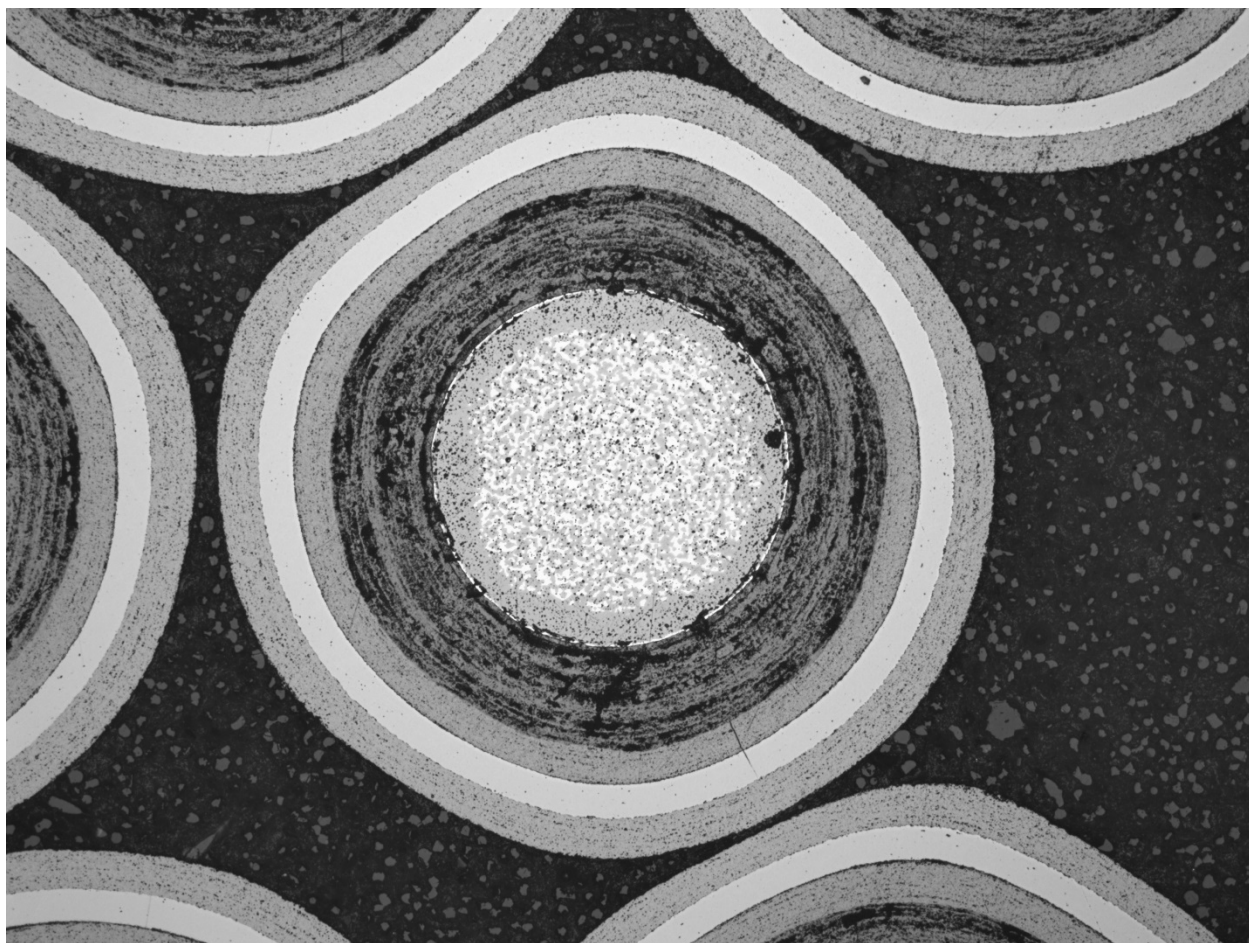




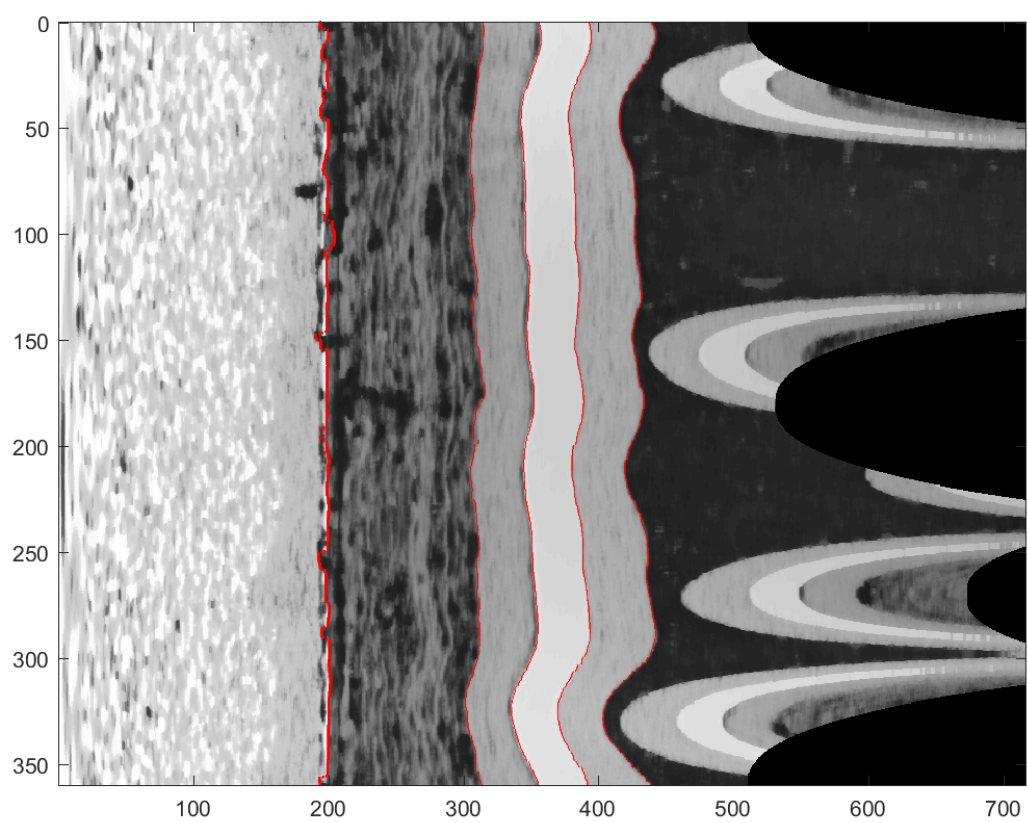
P16082301N091



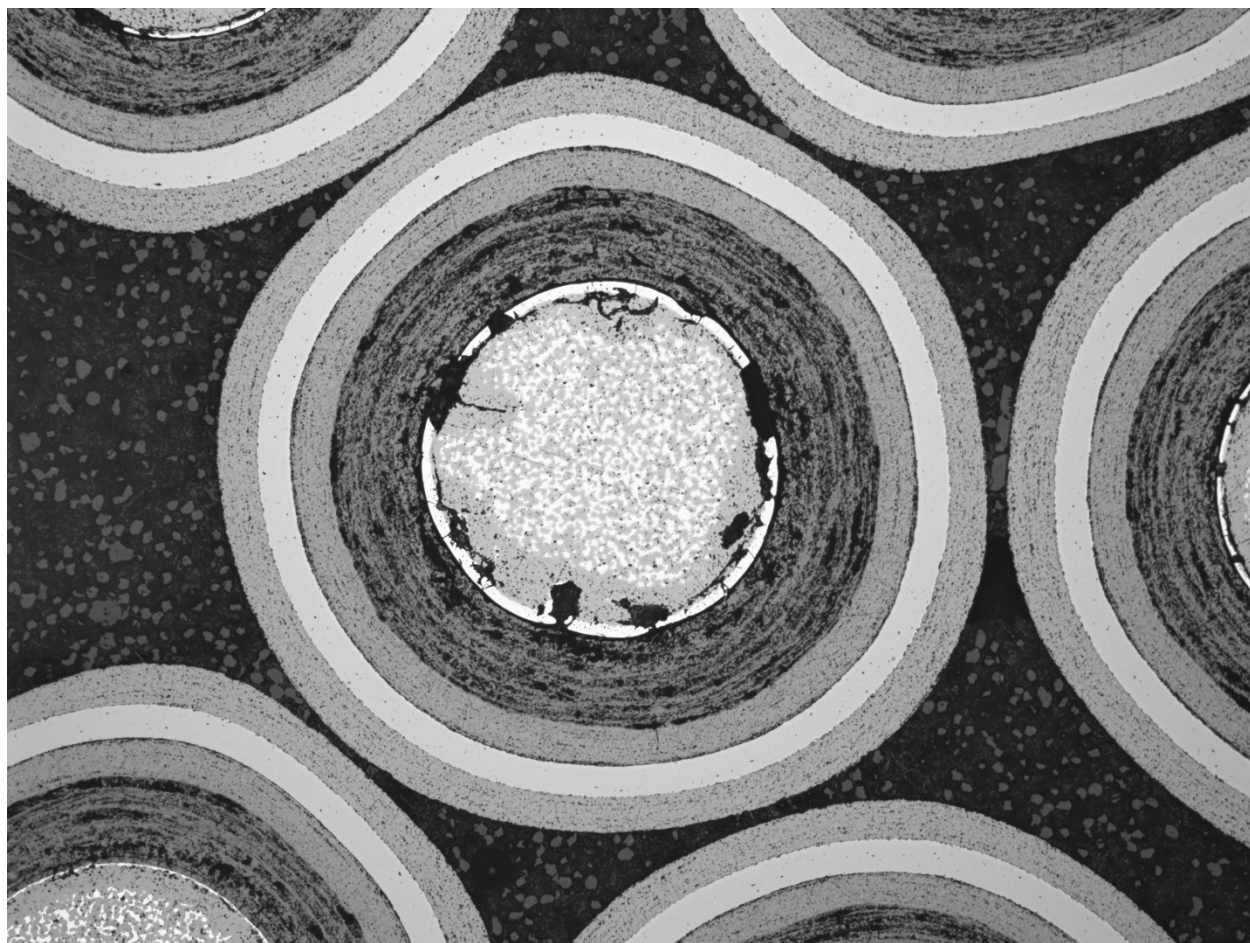
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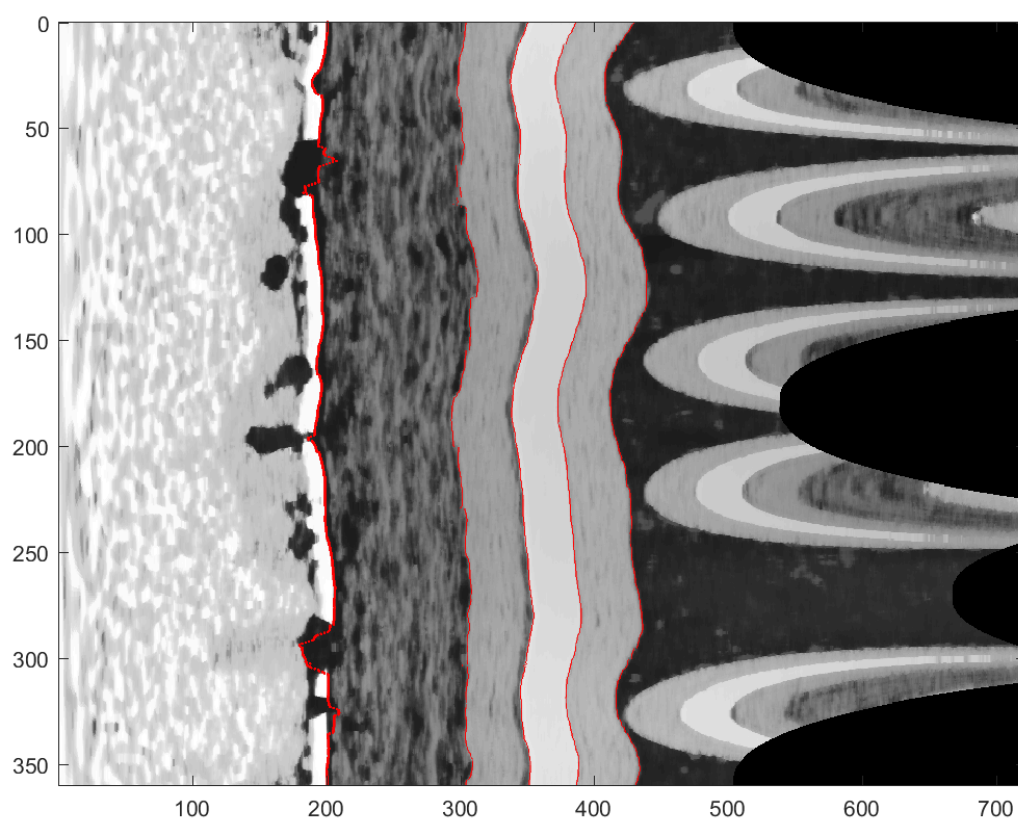
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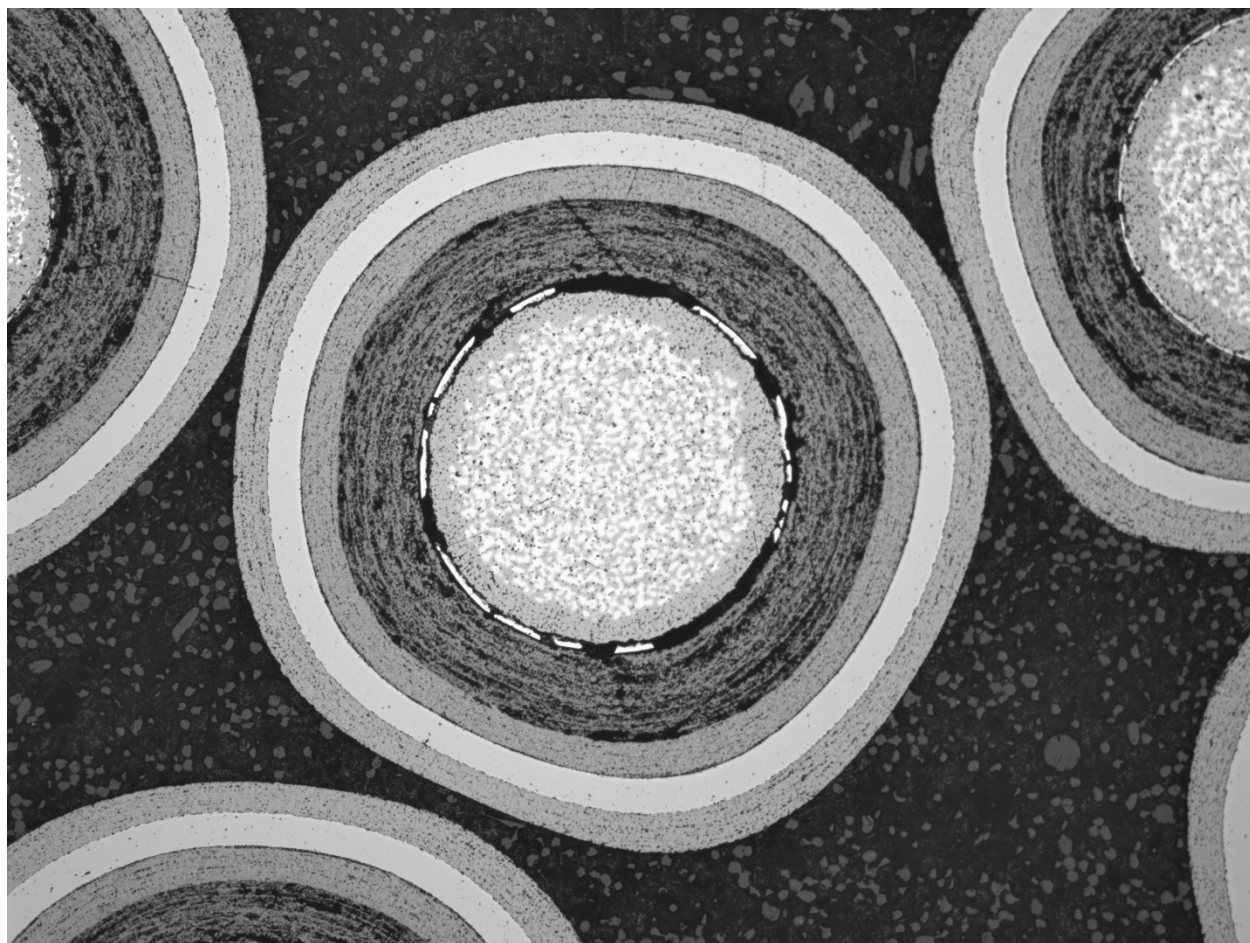


P16082301N093



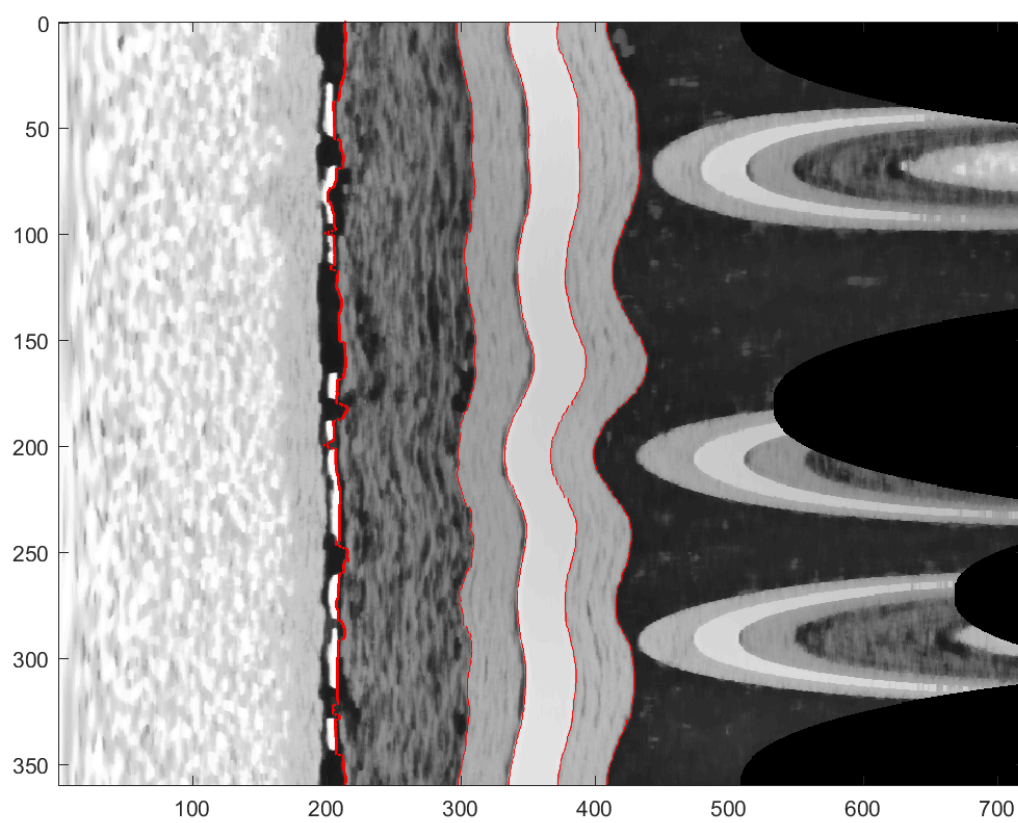
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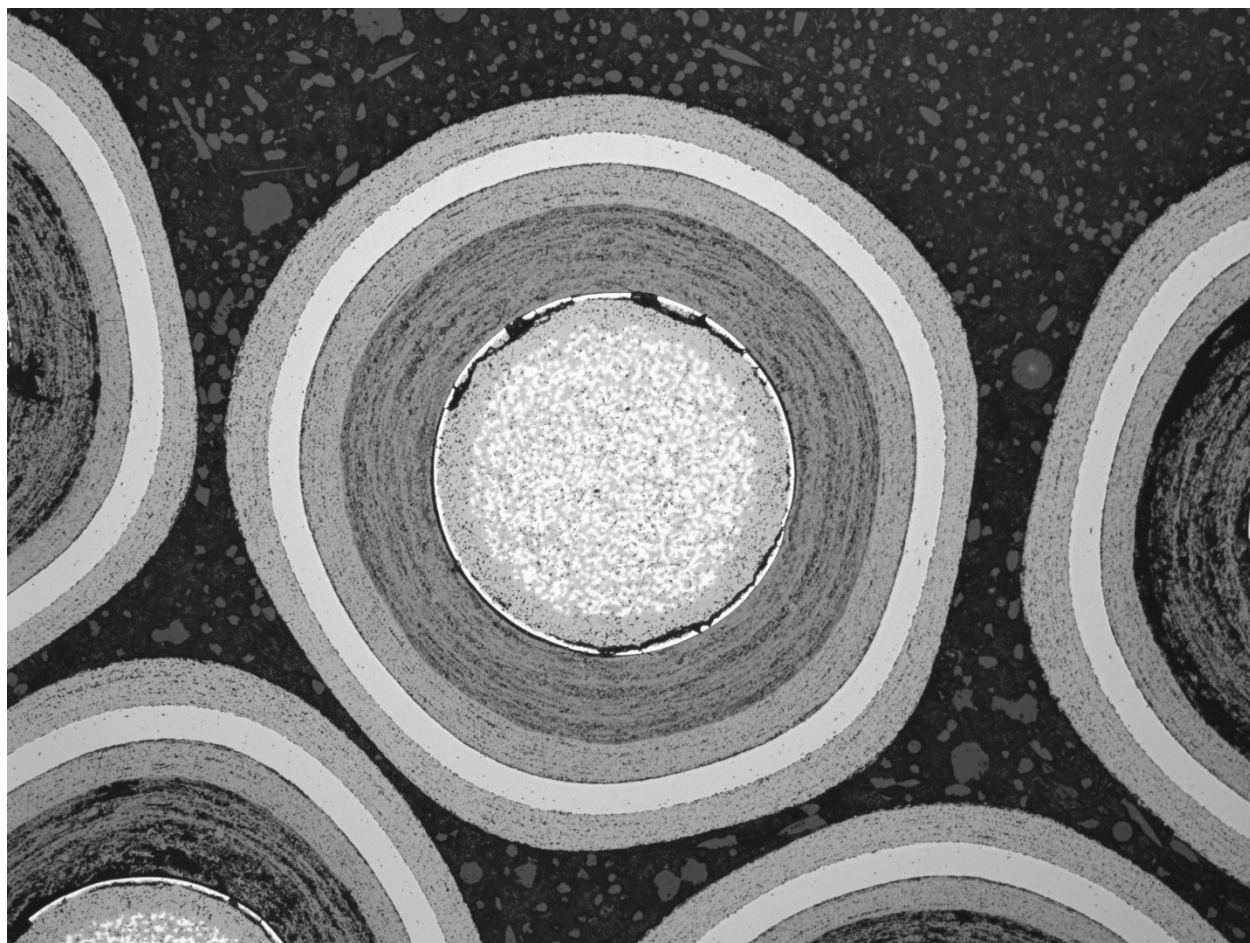


P16082301N095

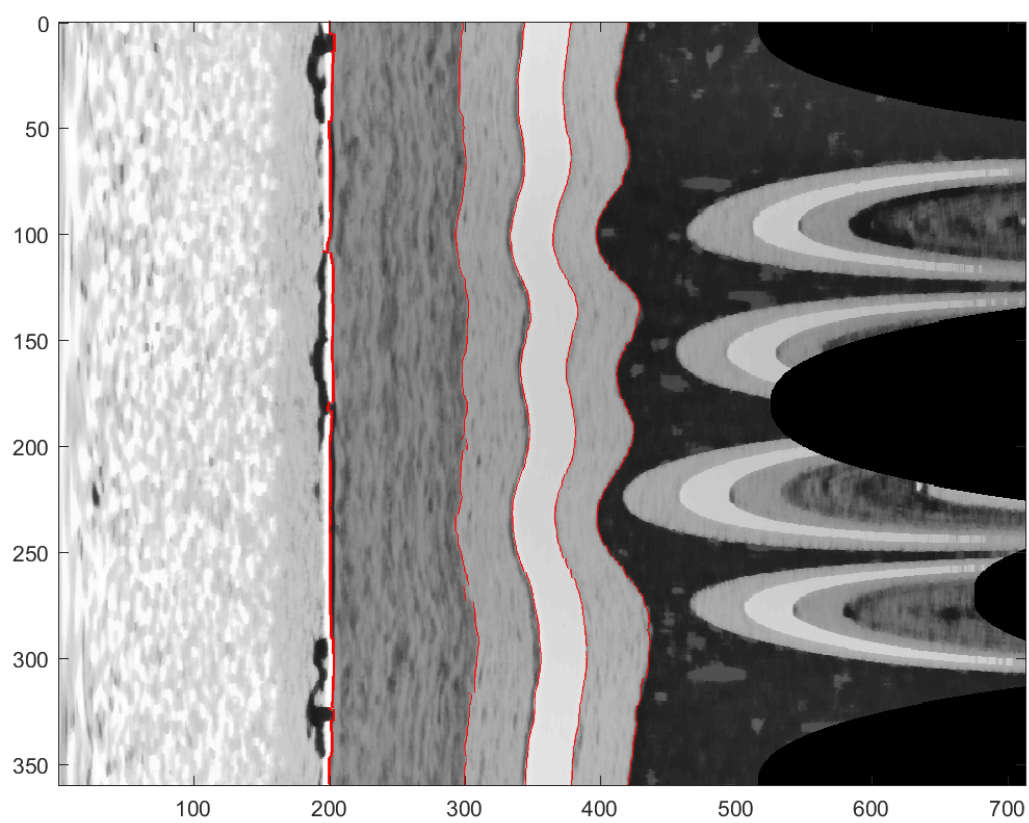




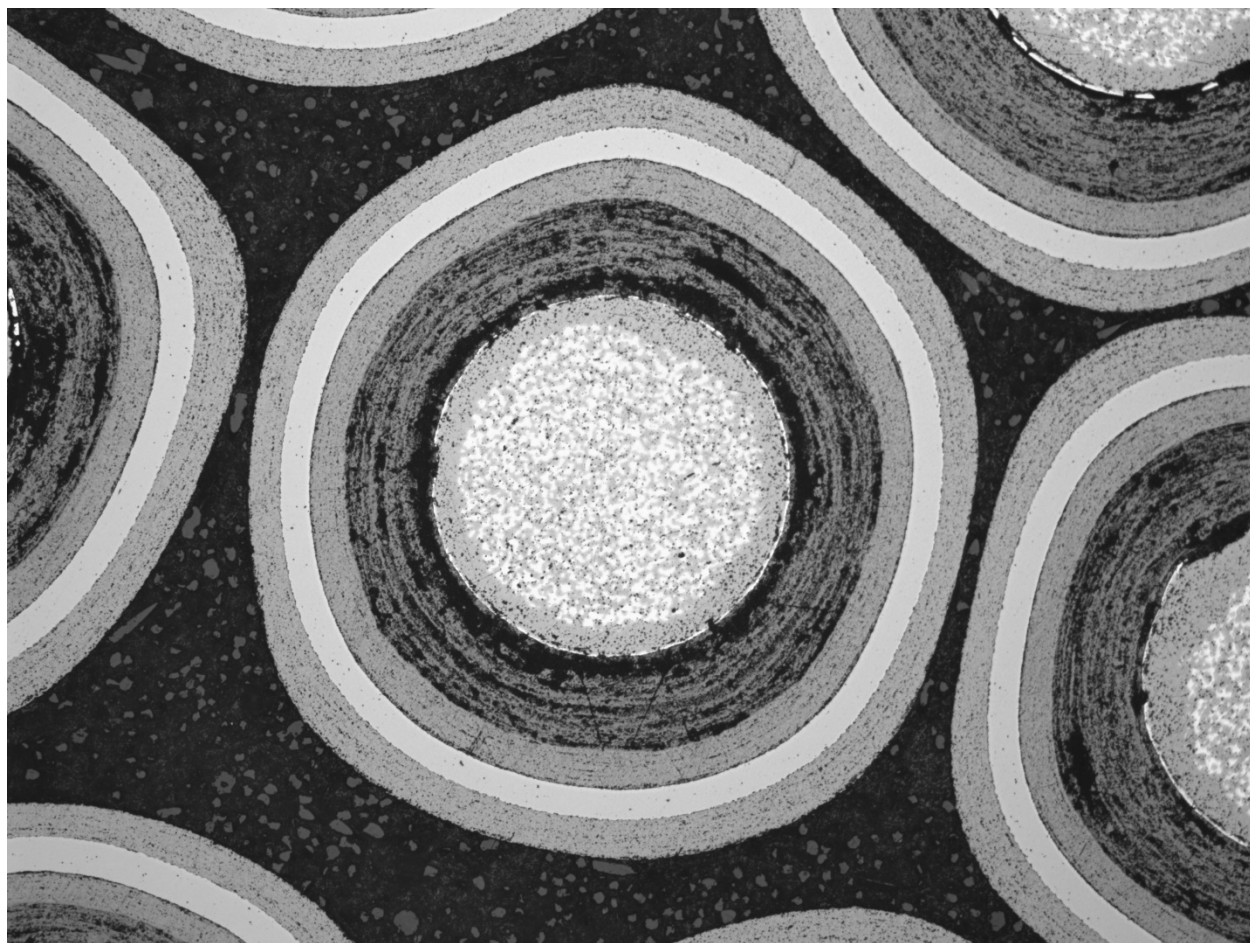
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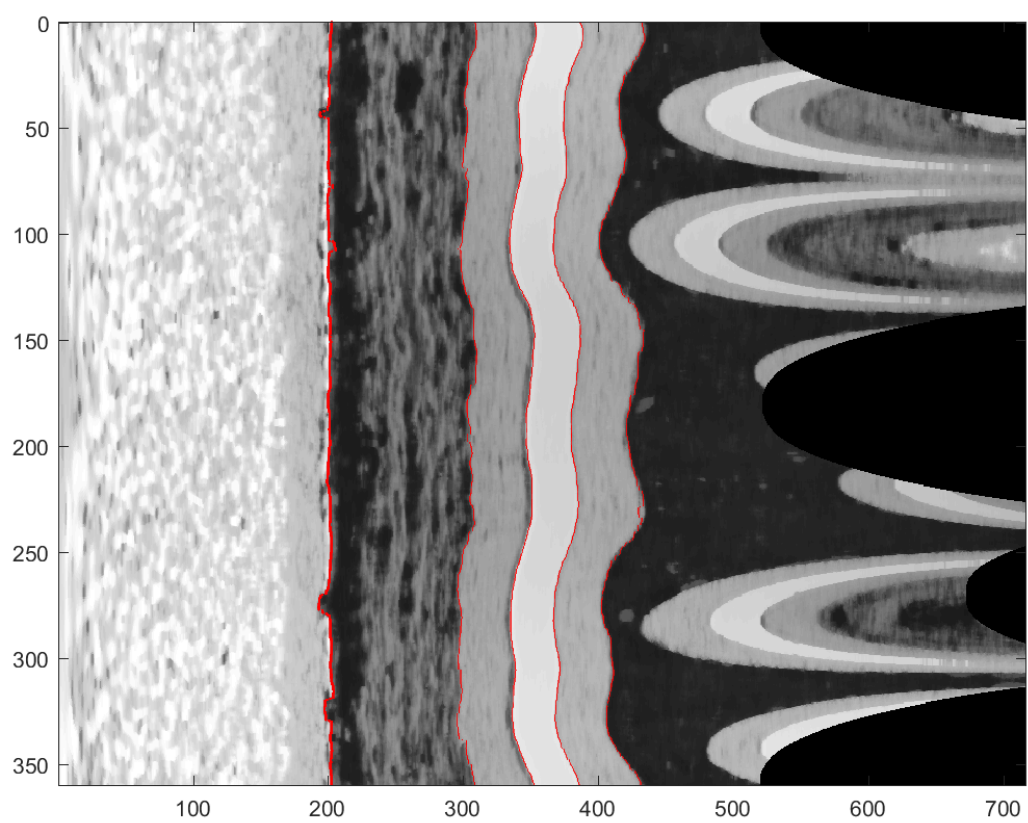
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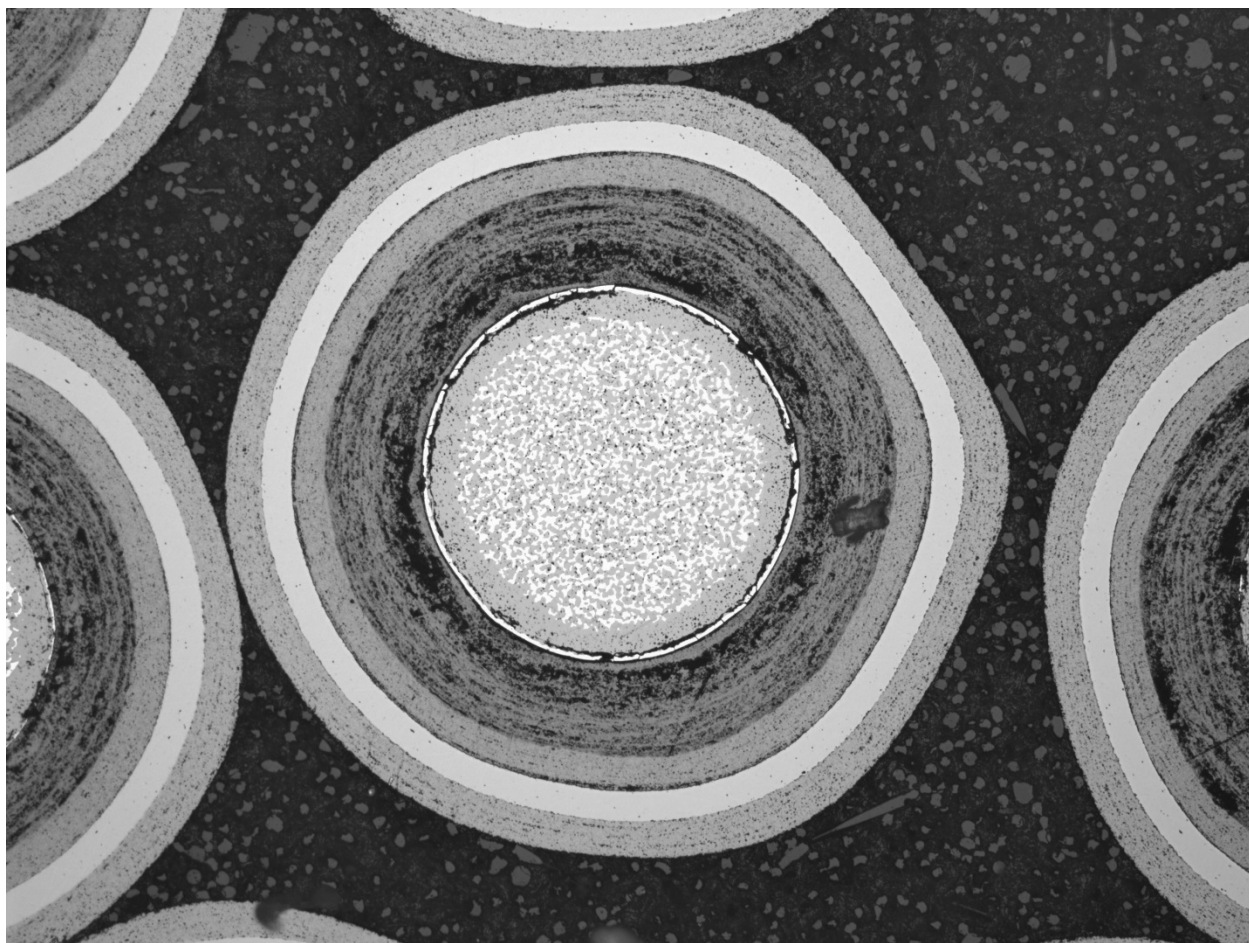
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P16082301N100

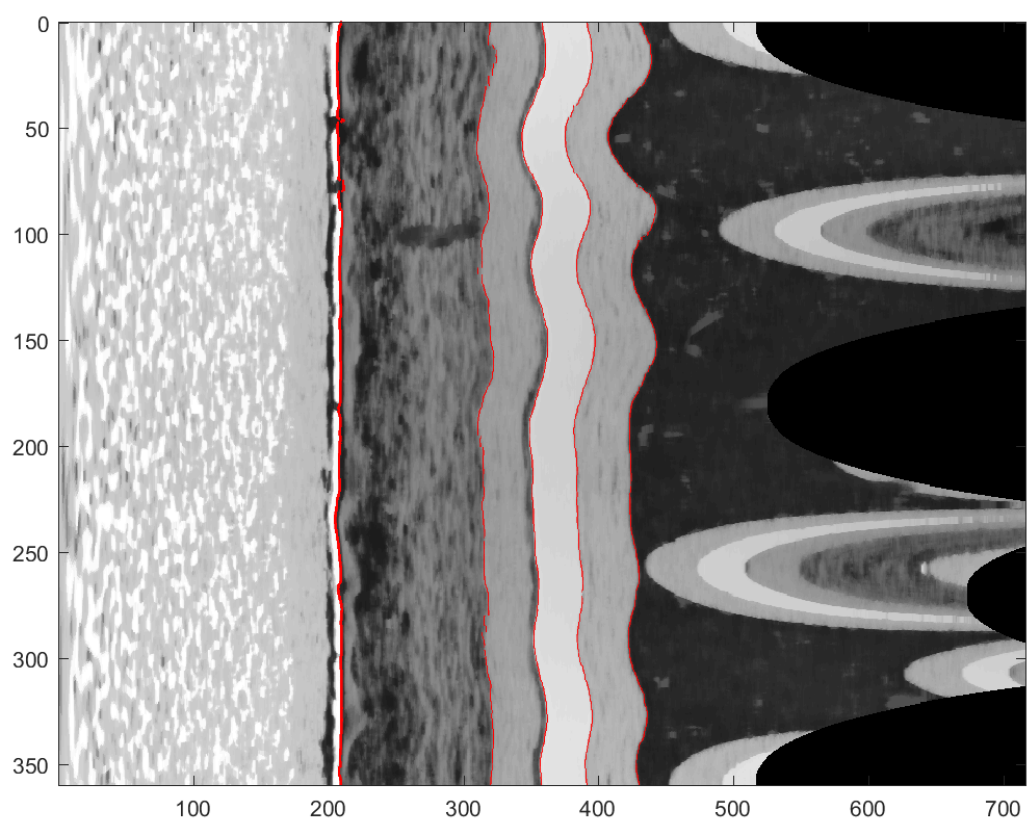


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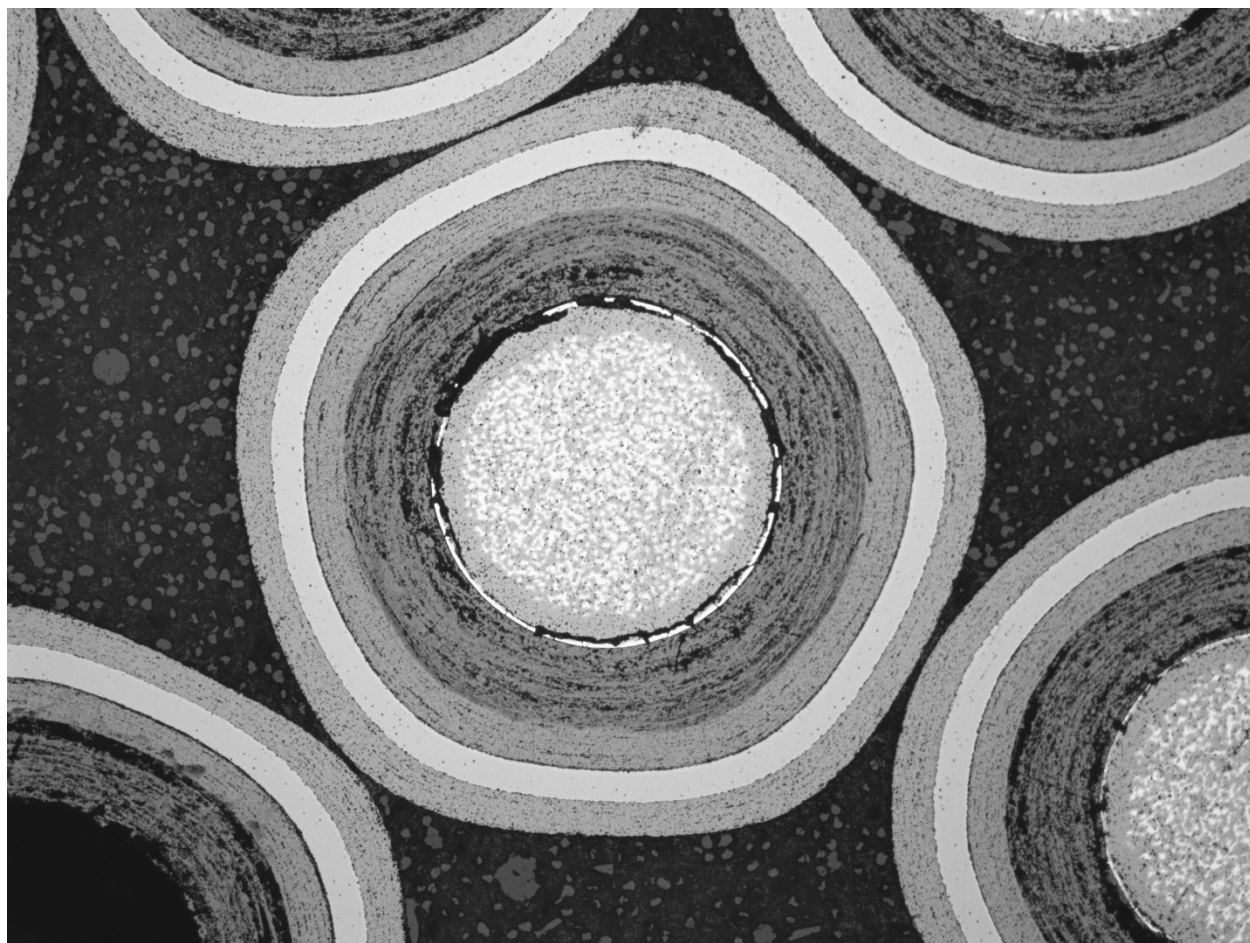
P16082301N101



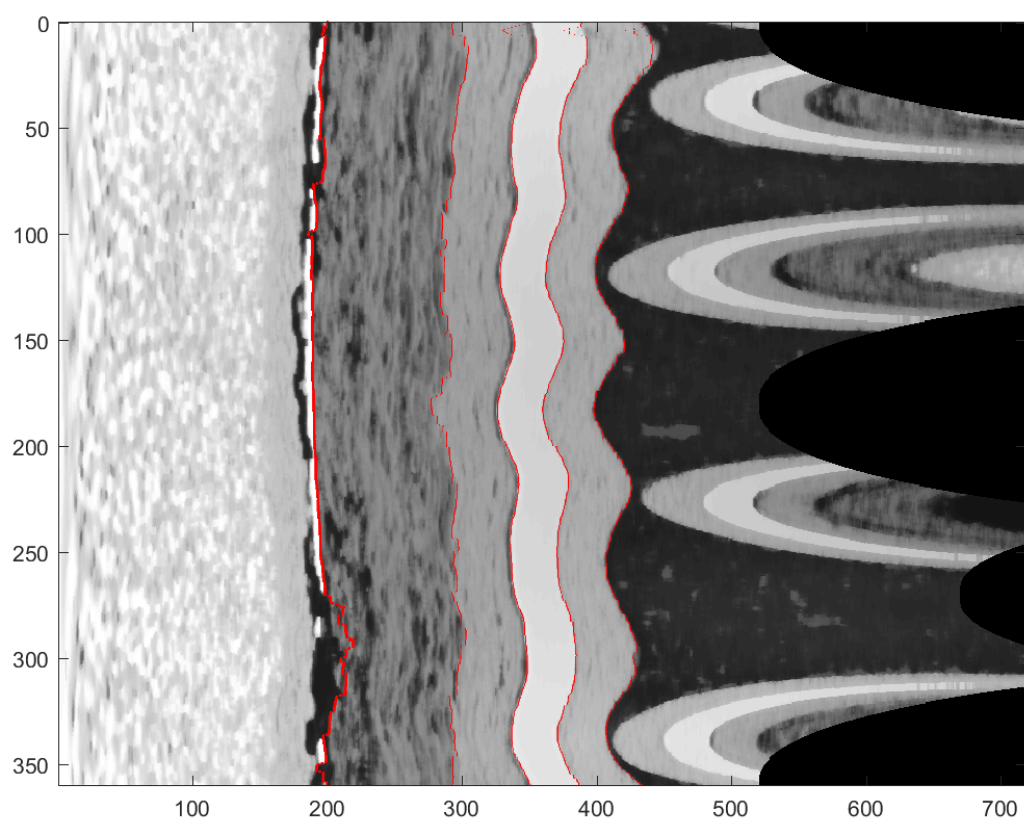


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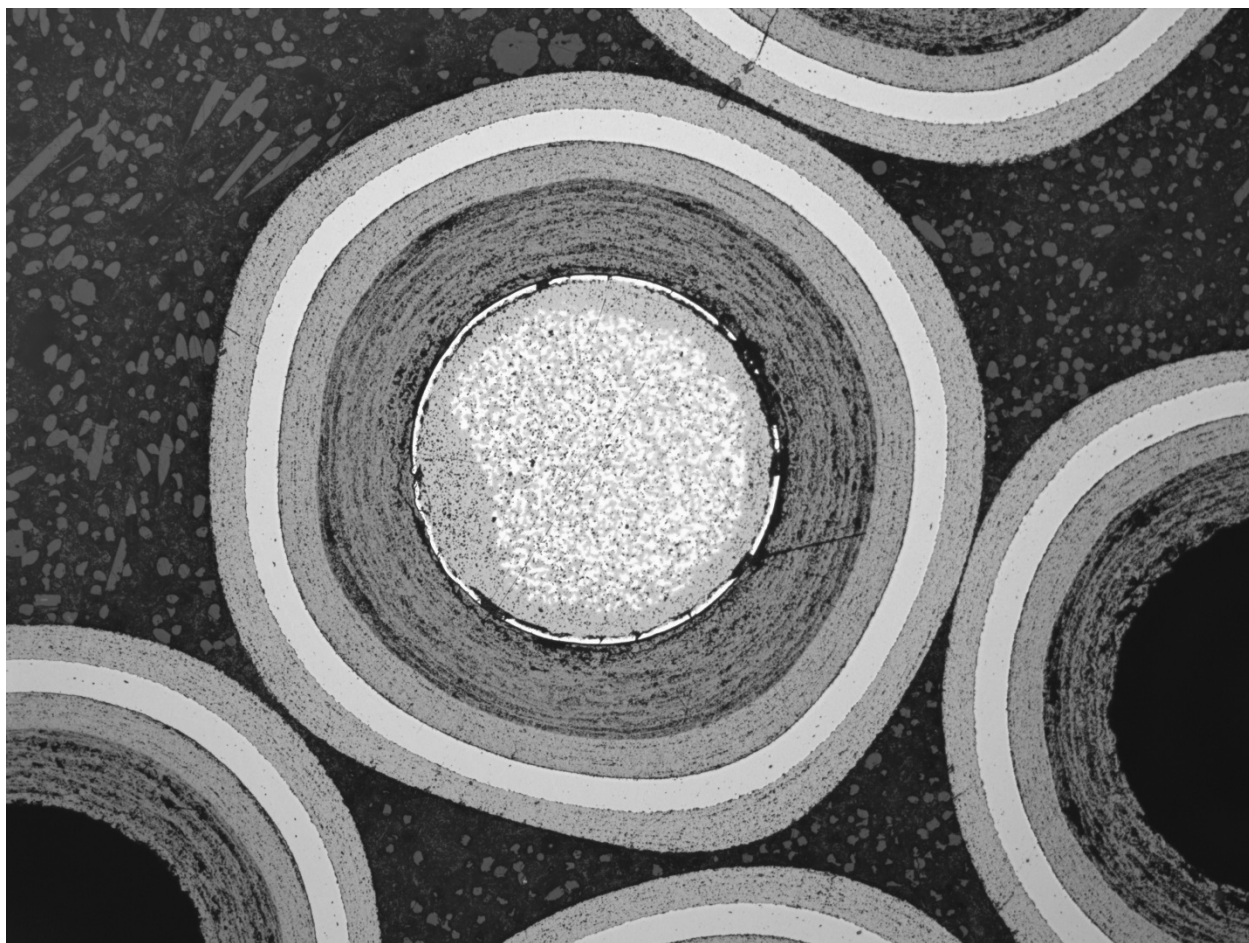




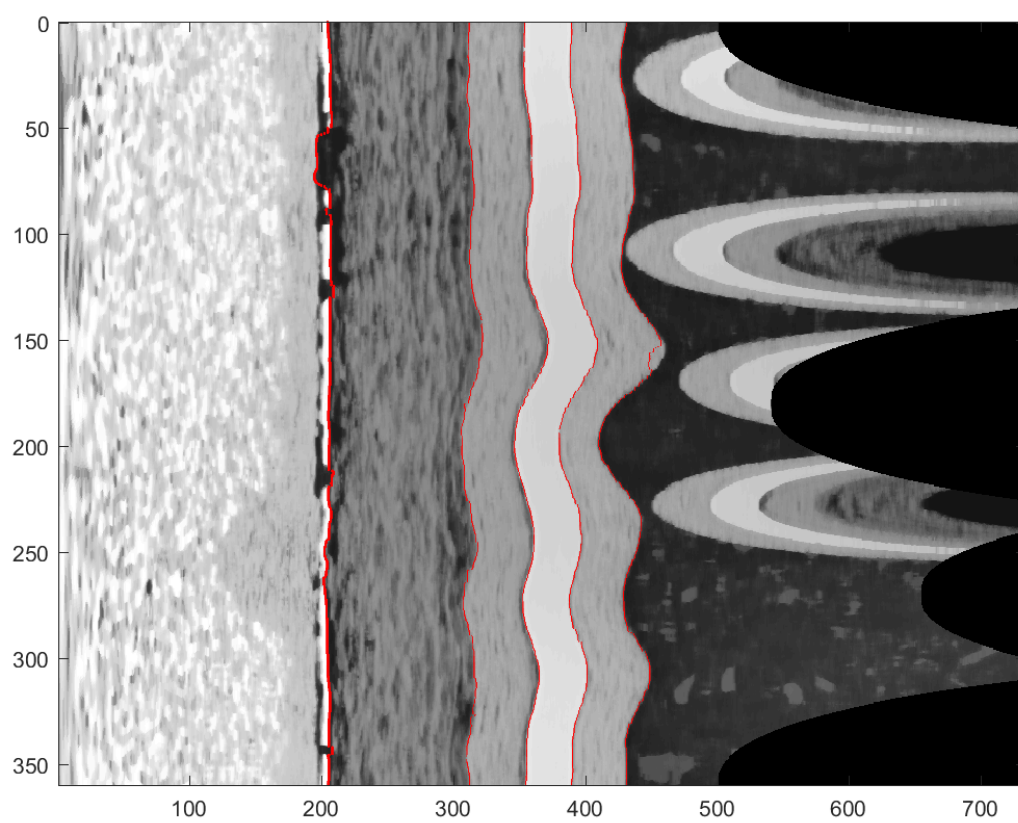
P16082301N102



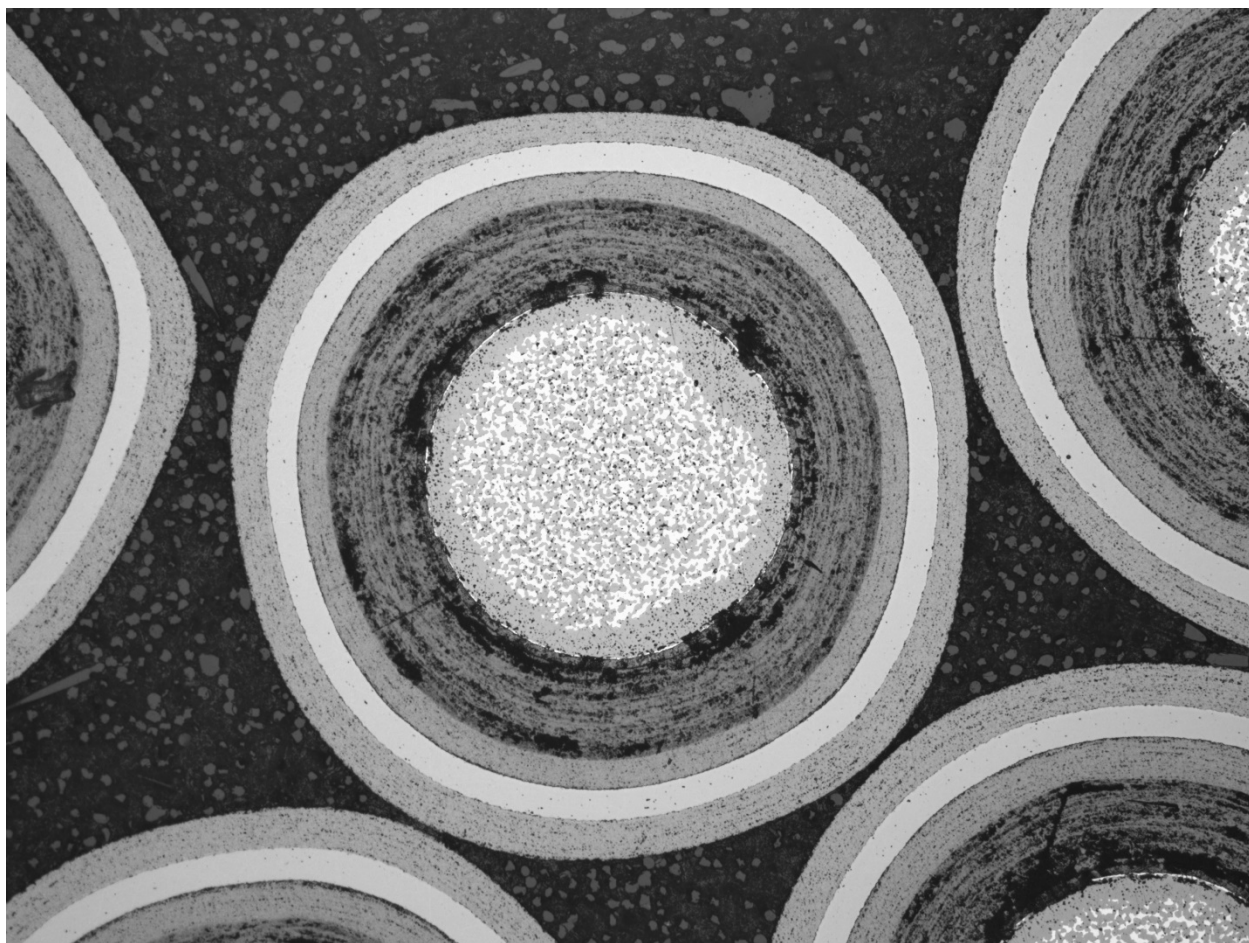
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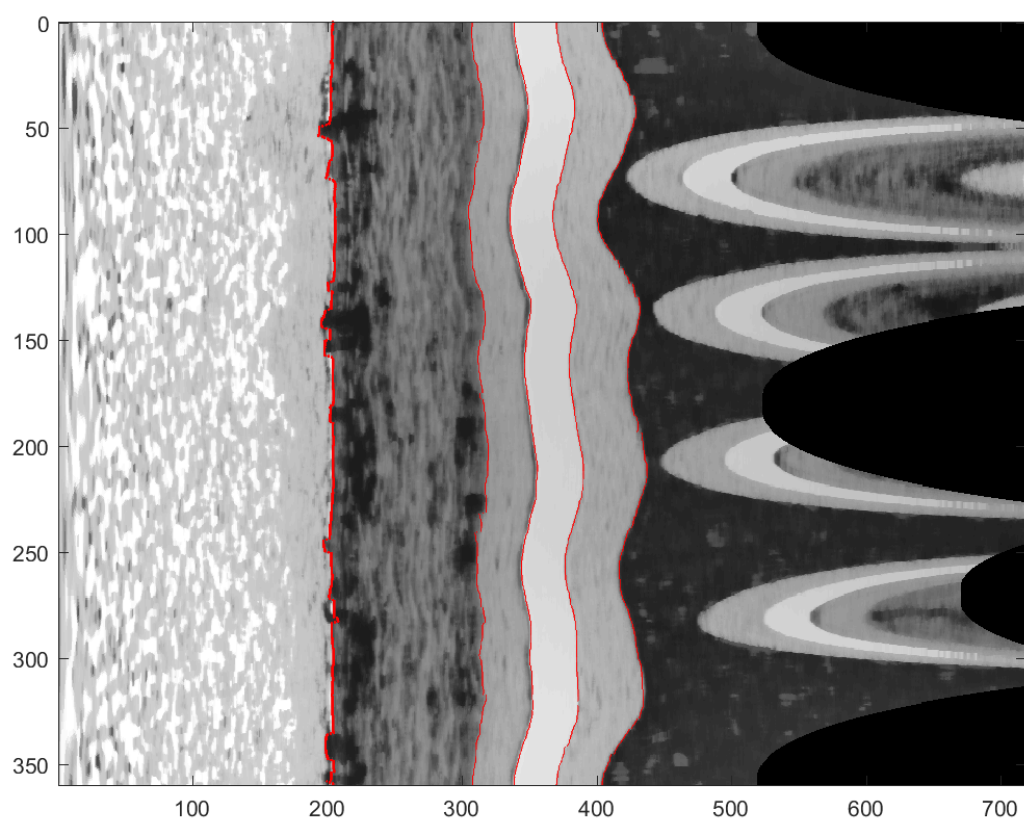
P16082301N103



**P16082301N103 unwrapped**

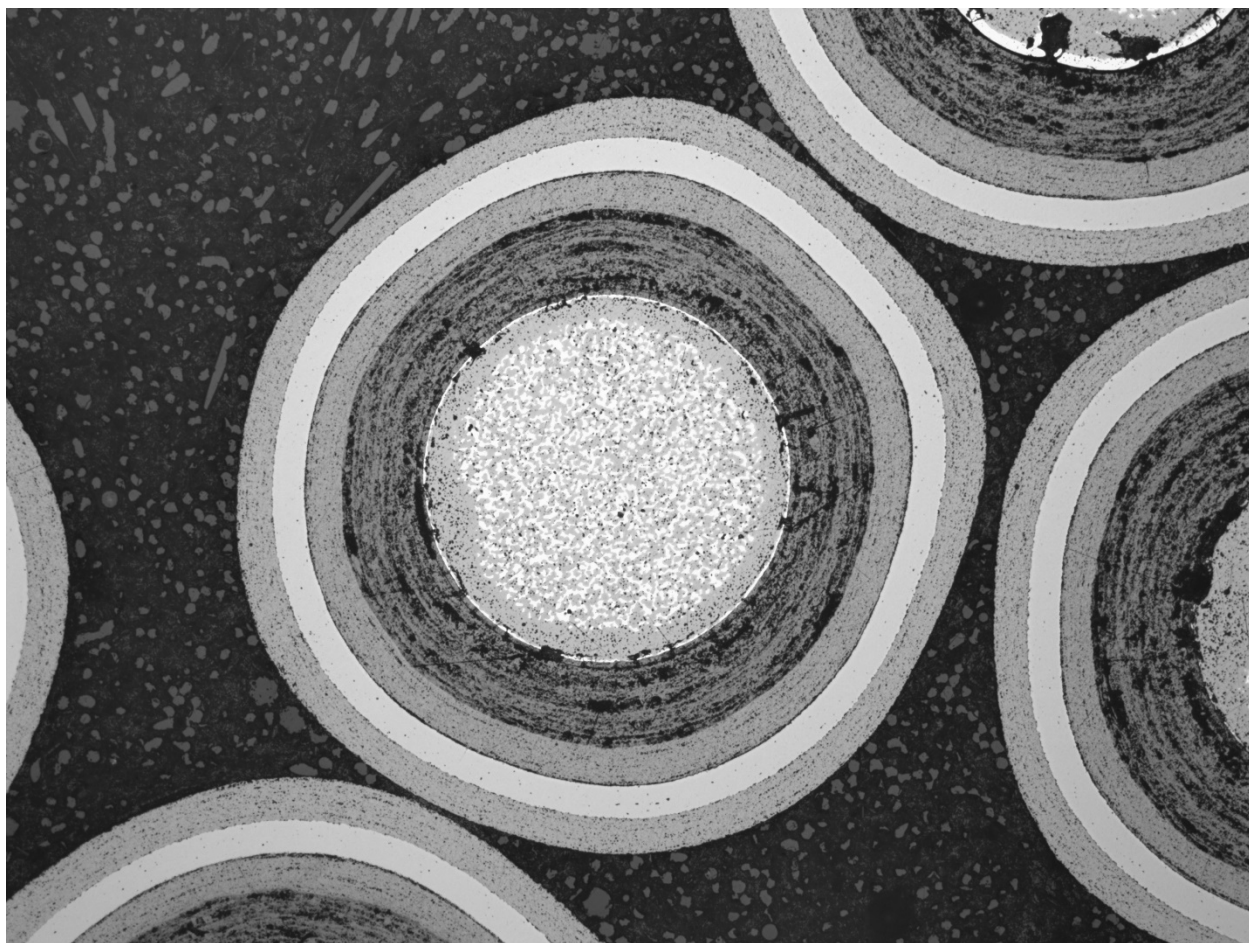


P16082301N104



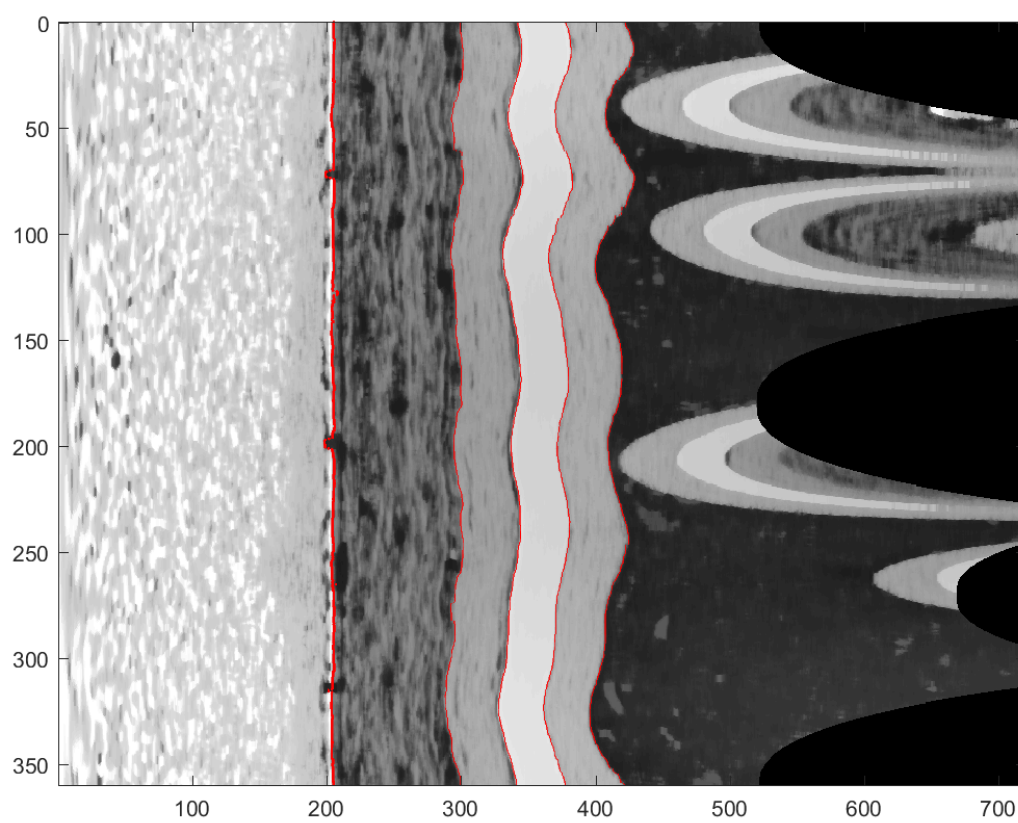
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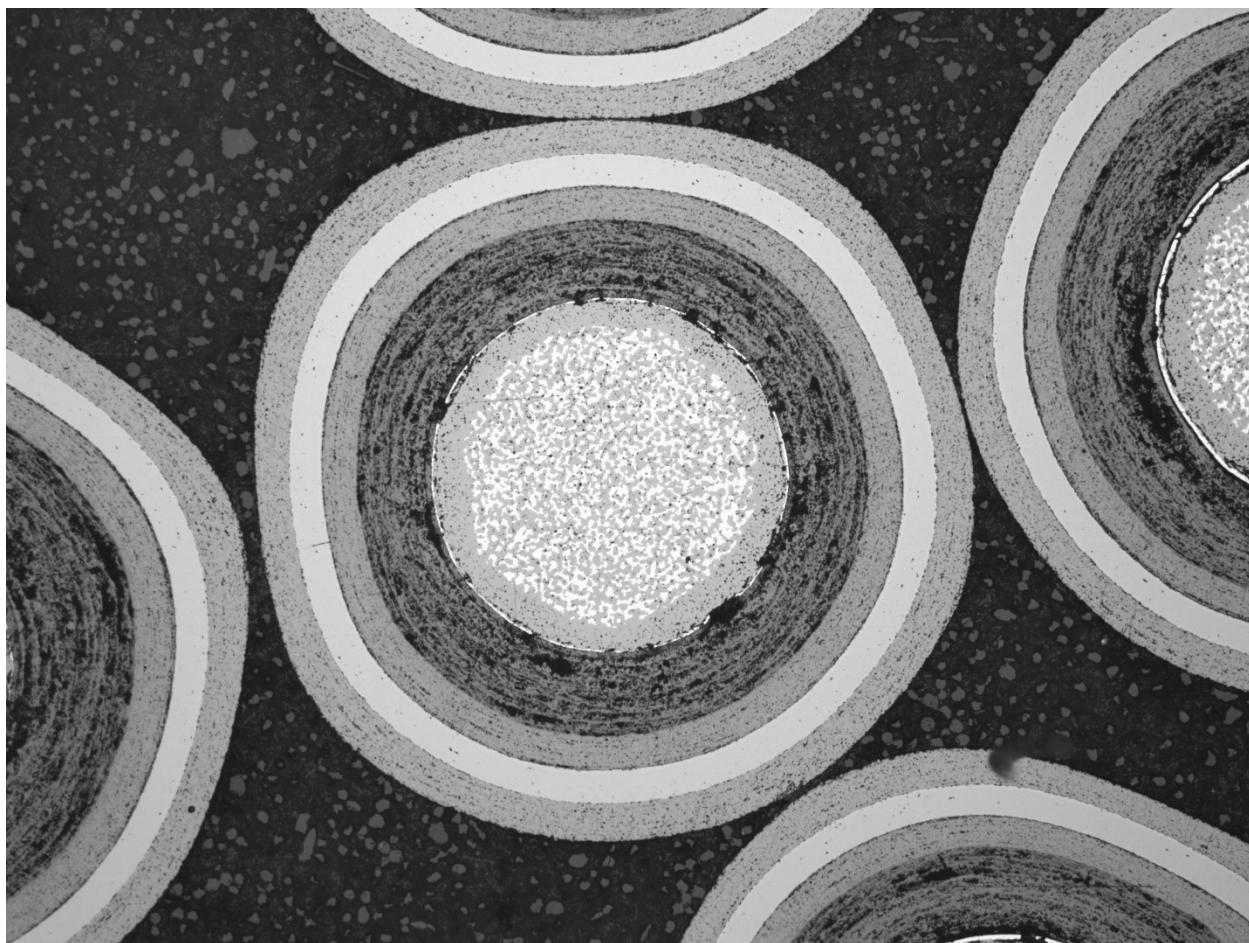


P16082301N105

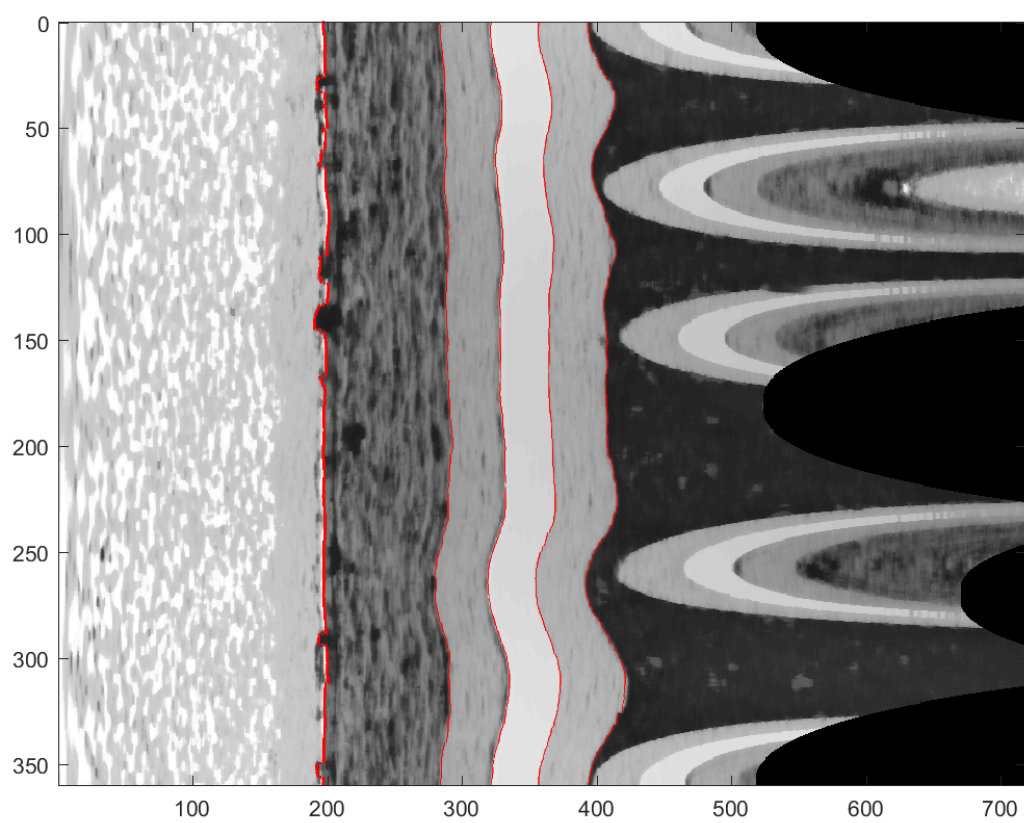




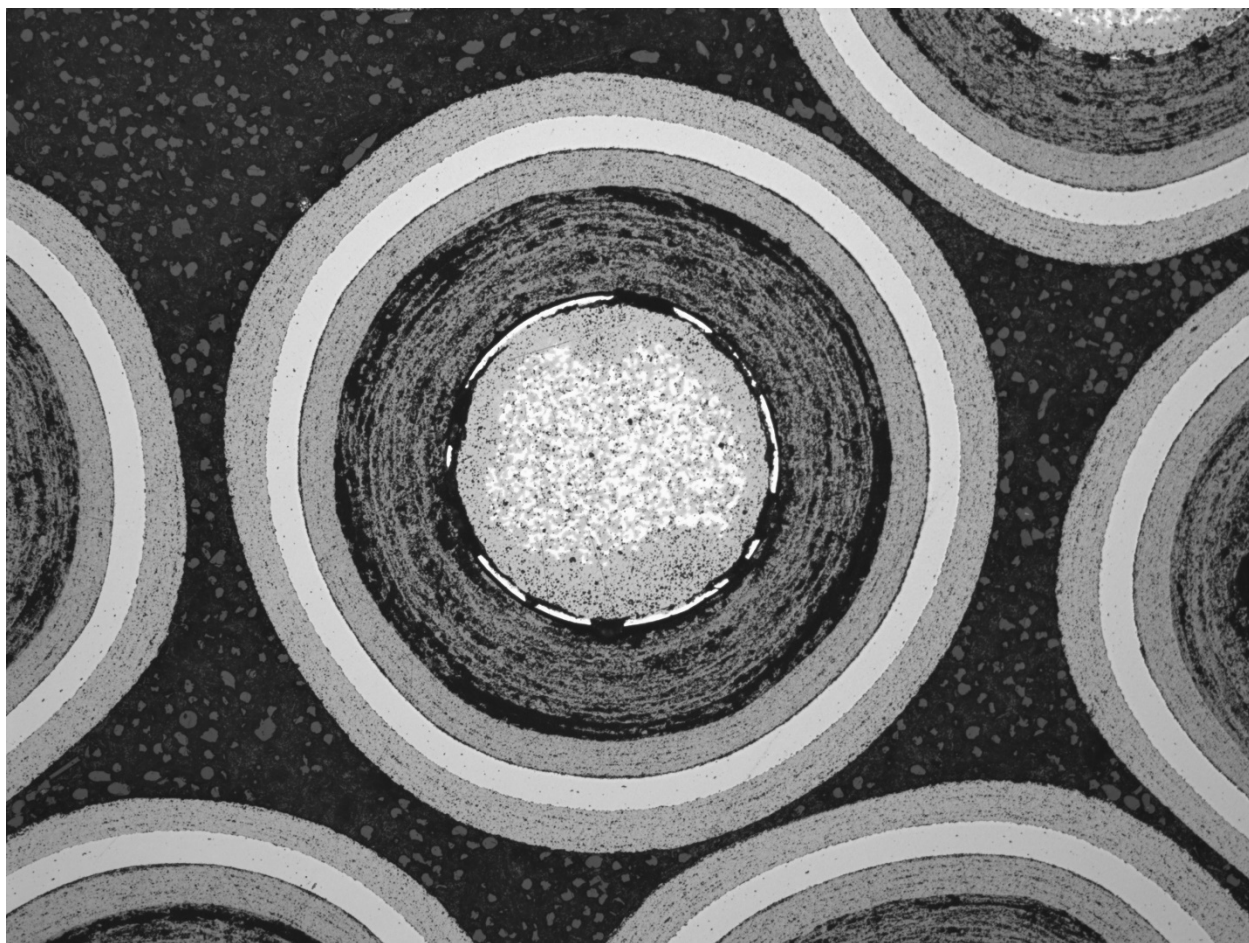
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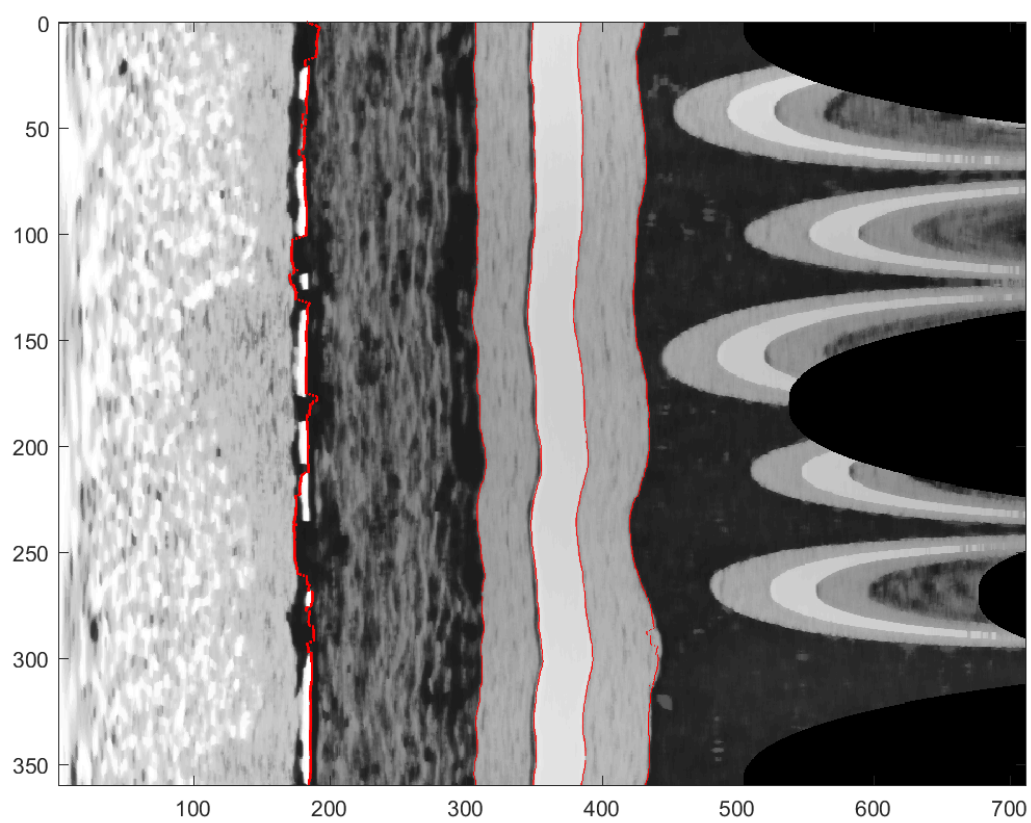
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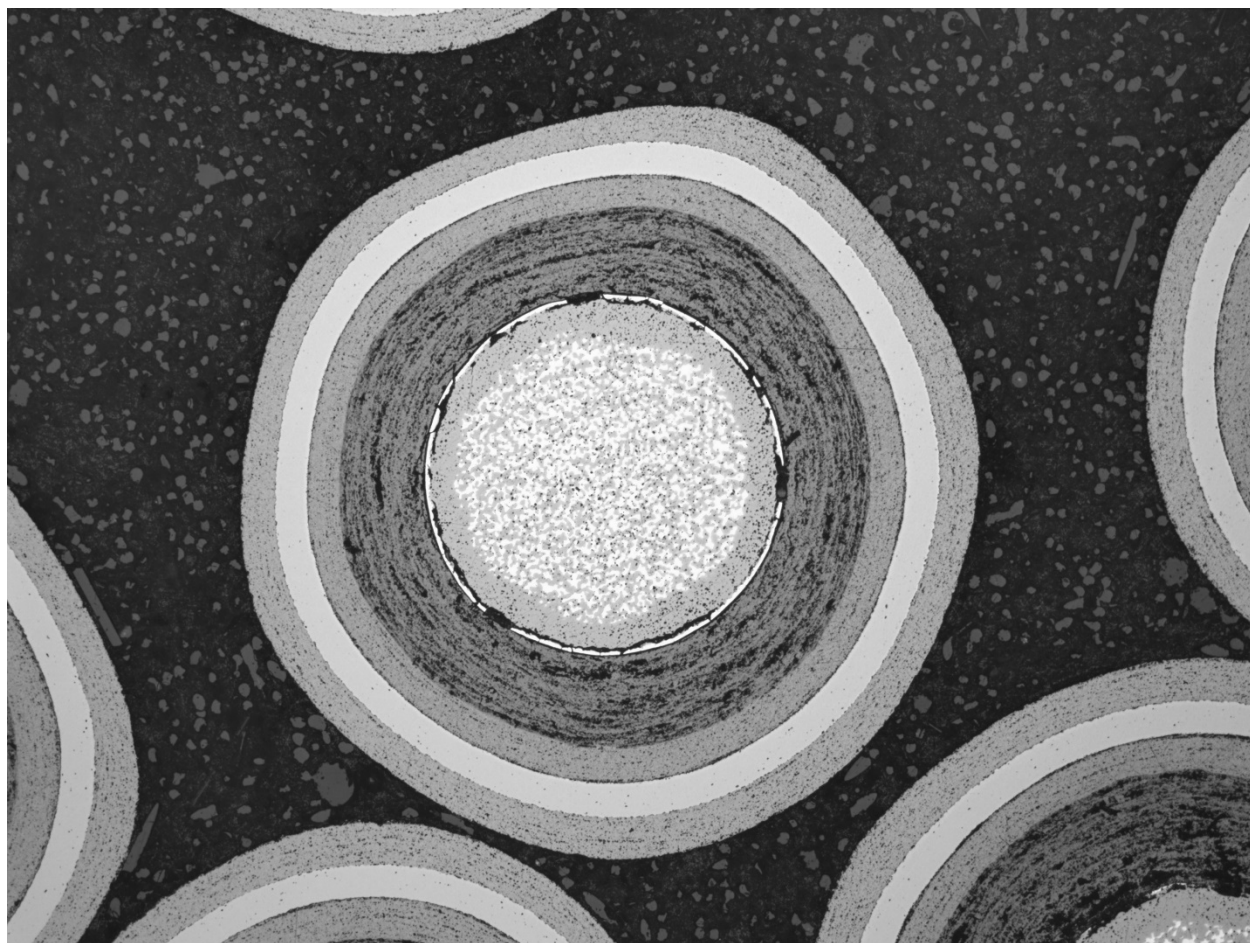
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P16082301N107

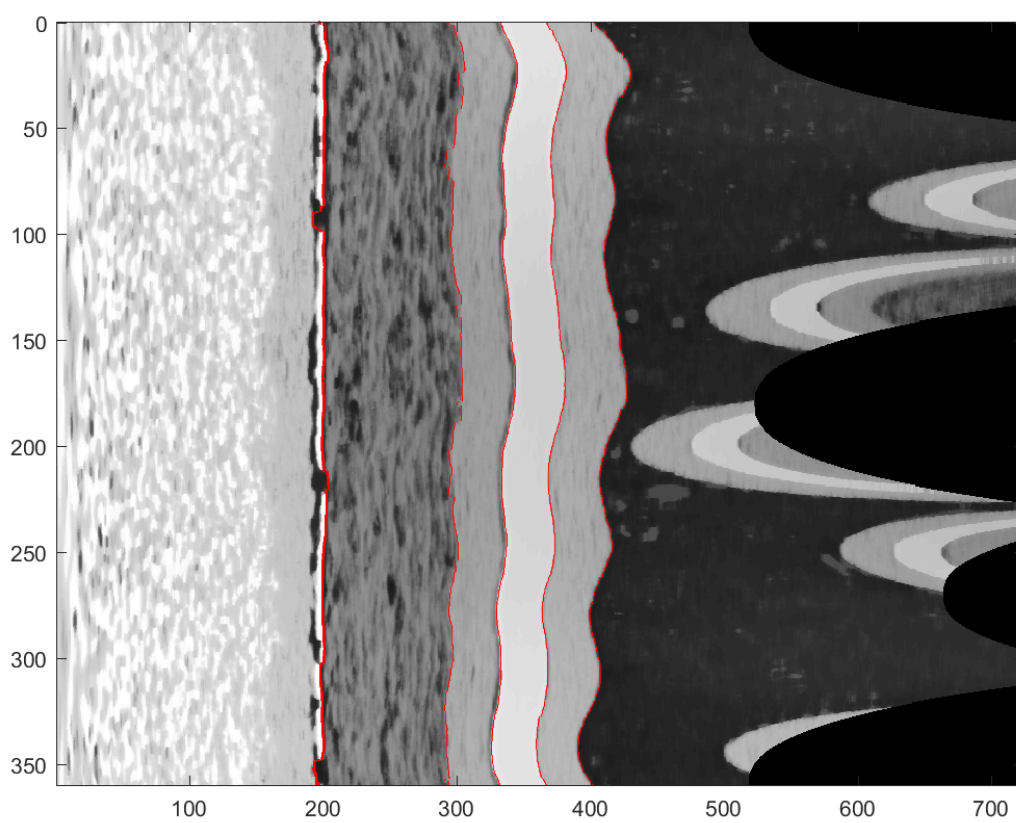


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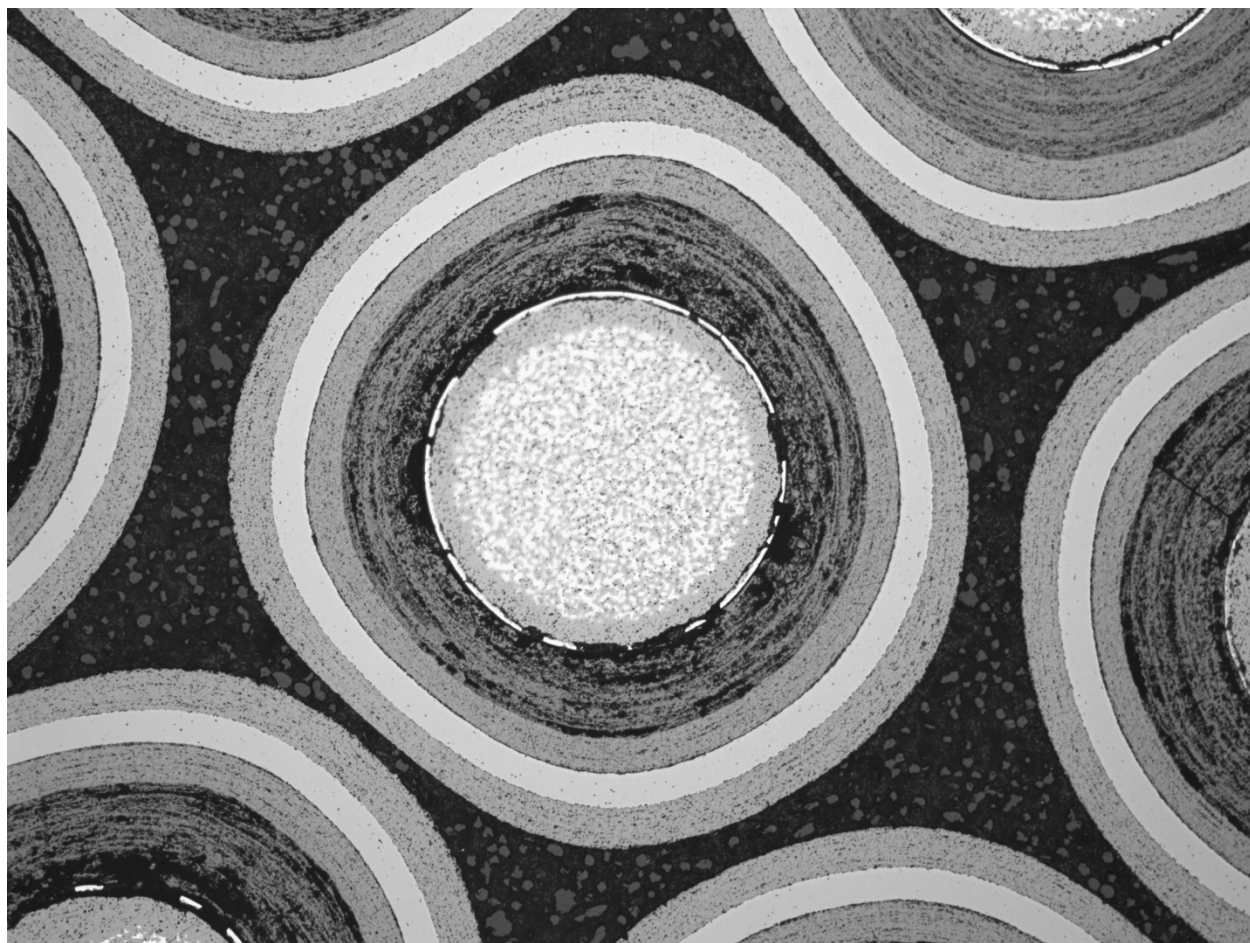
P16082301N109



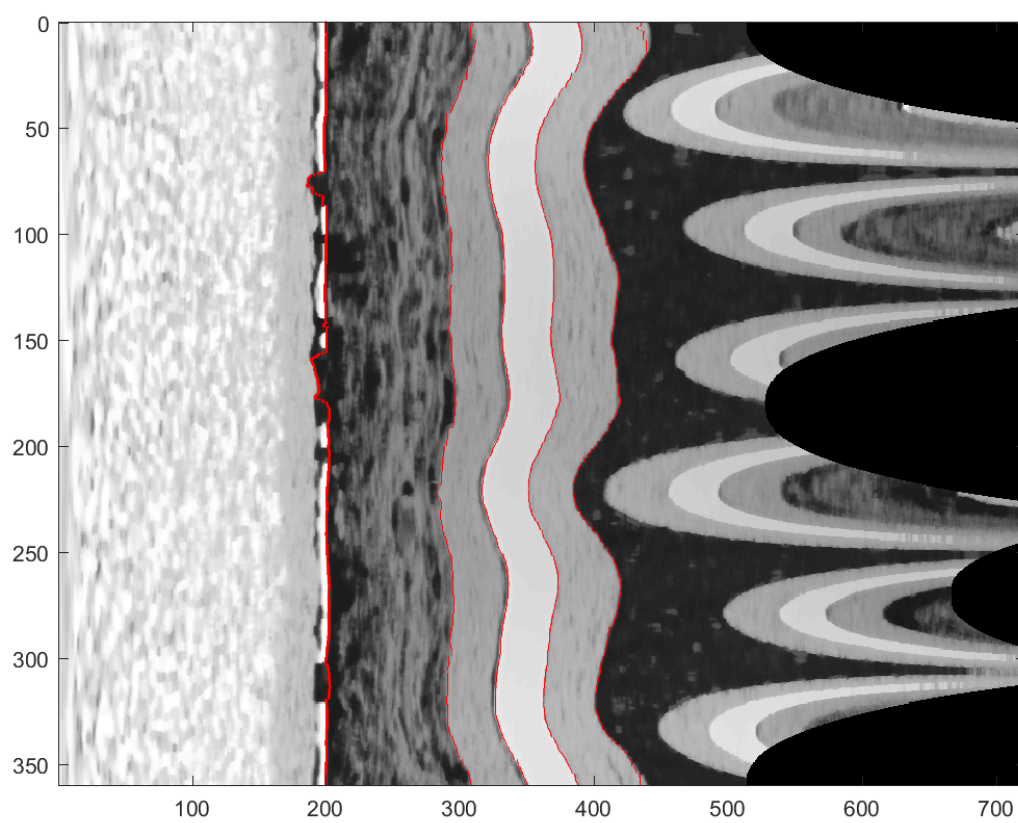


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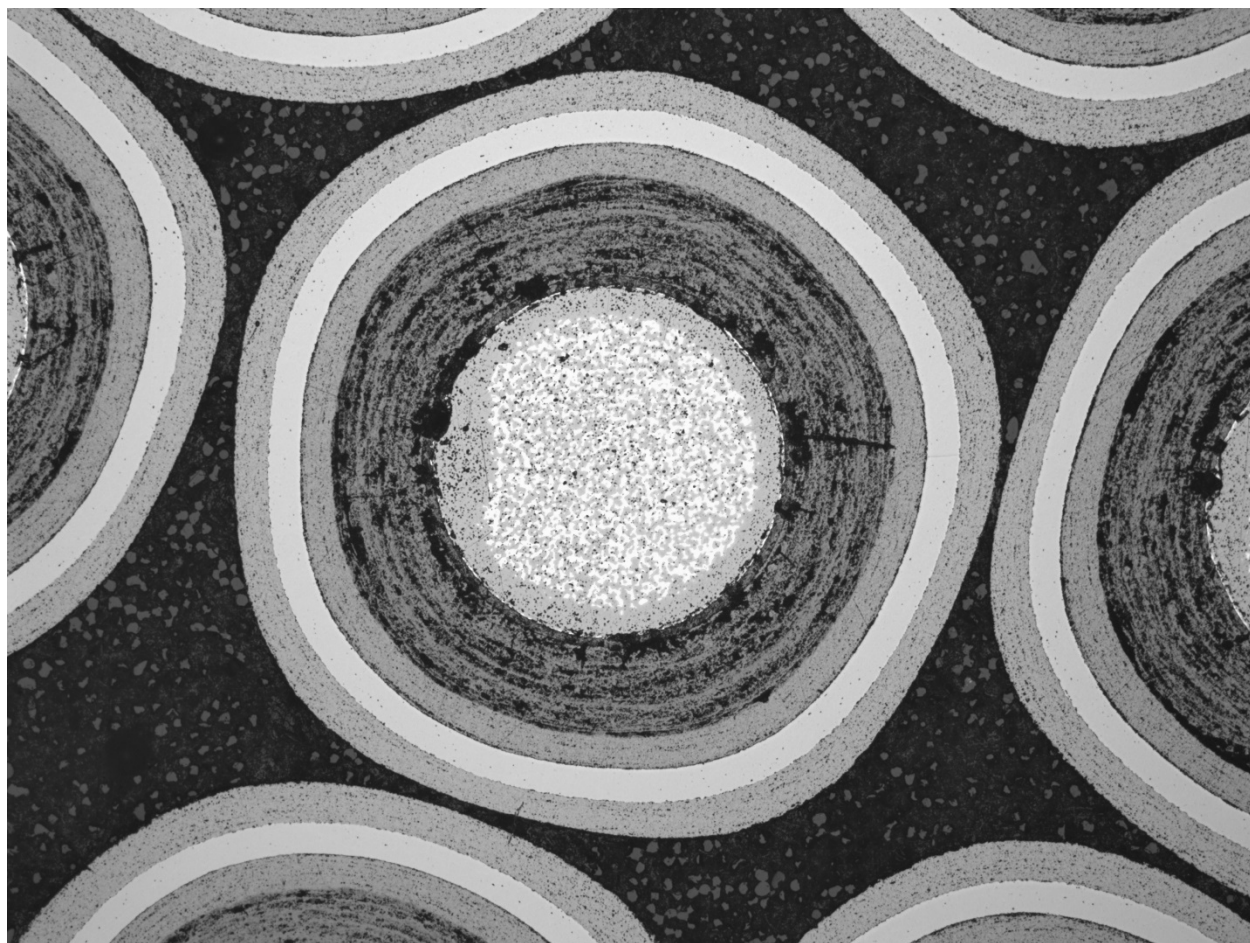




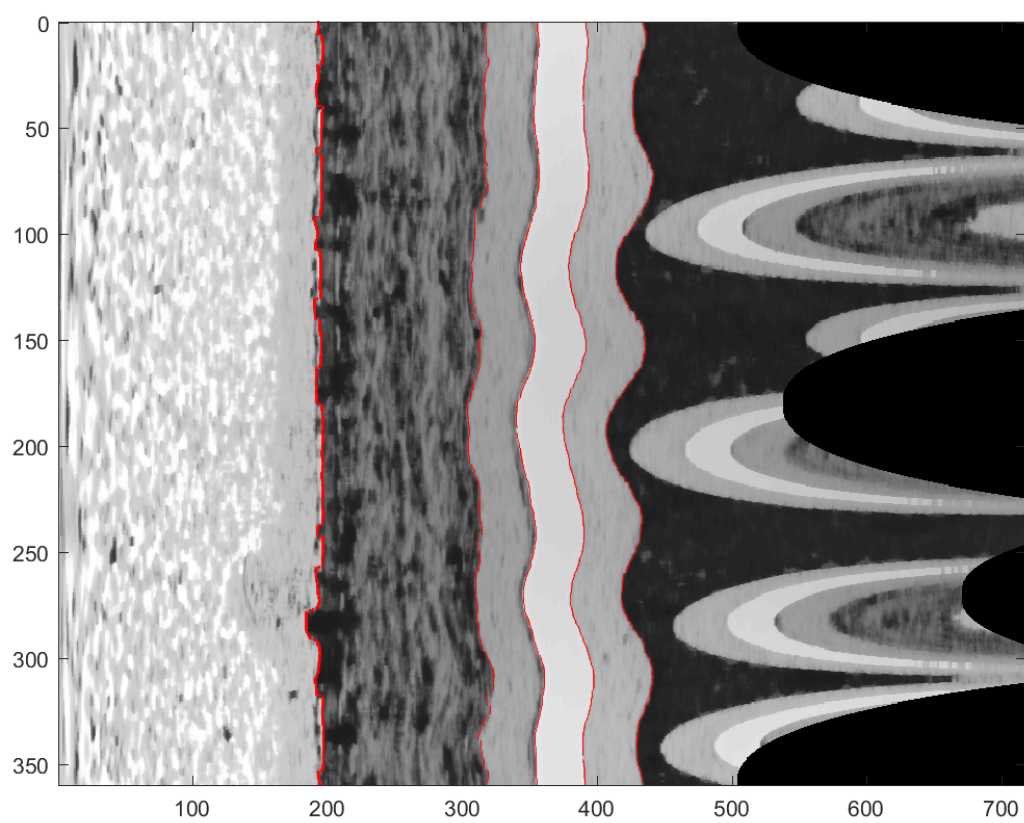
P16082301N110



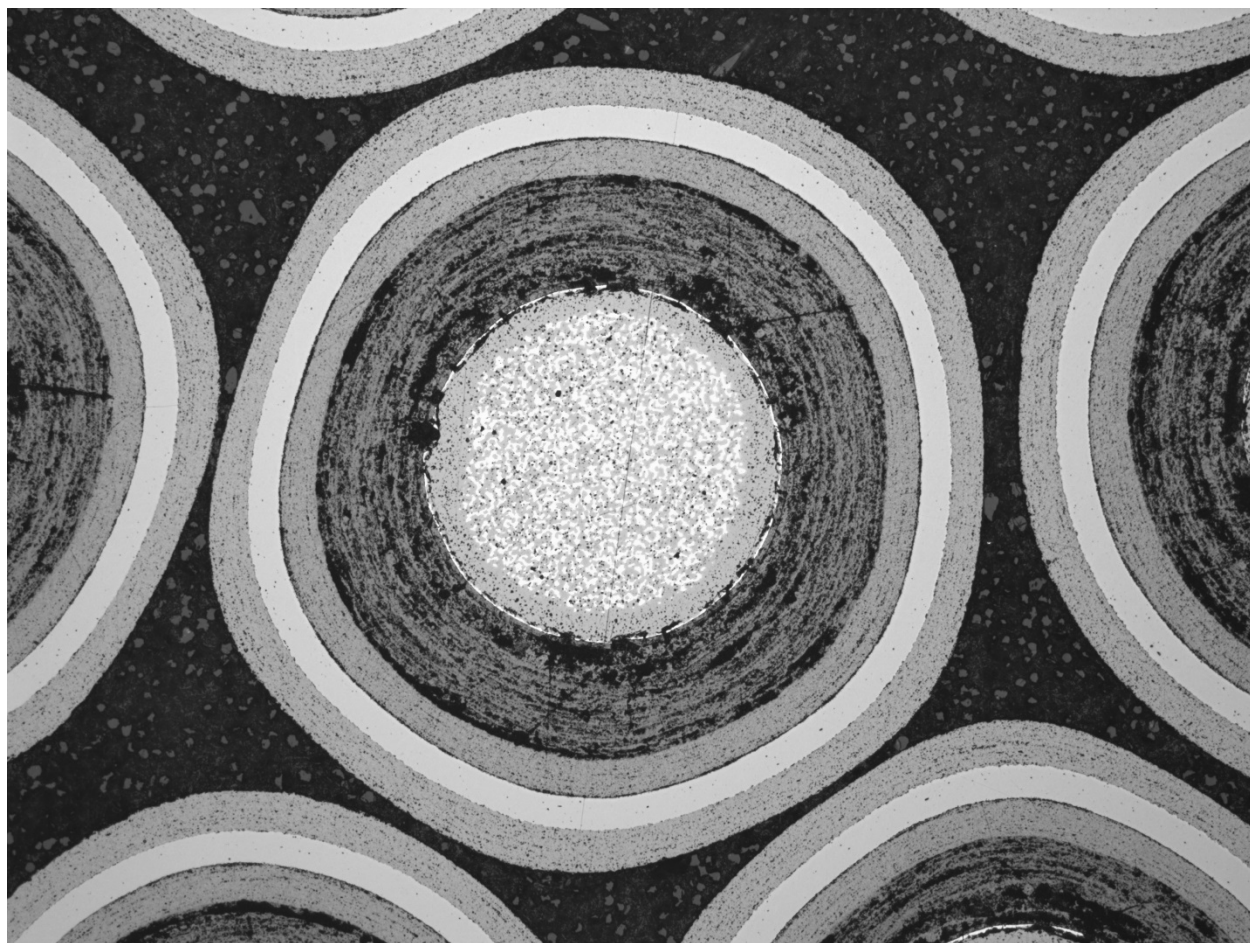
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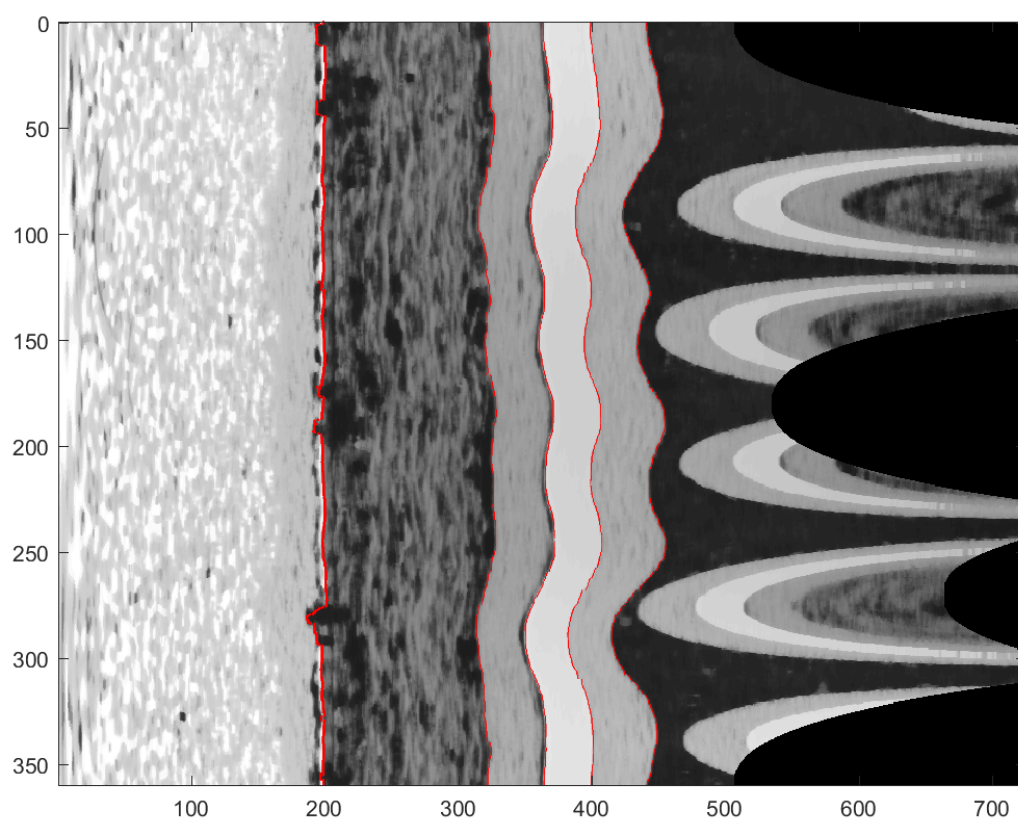
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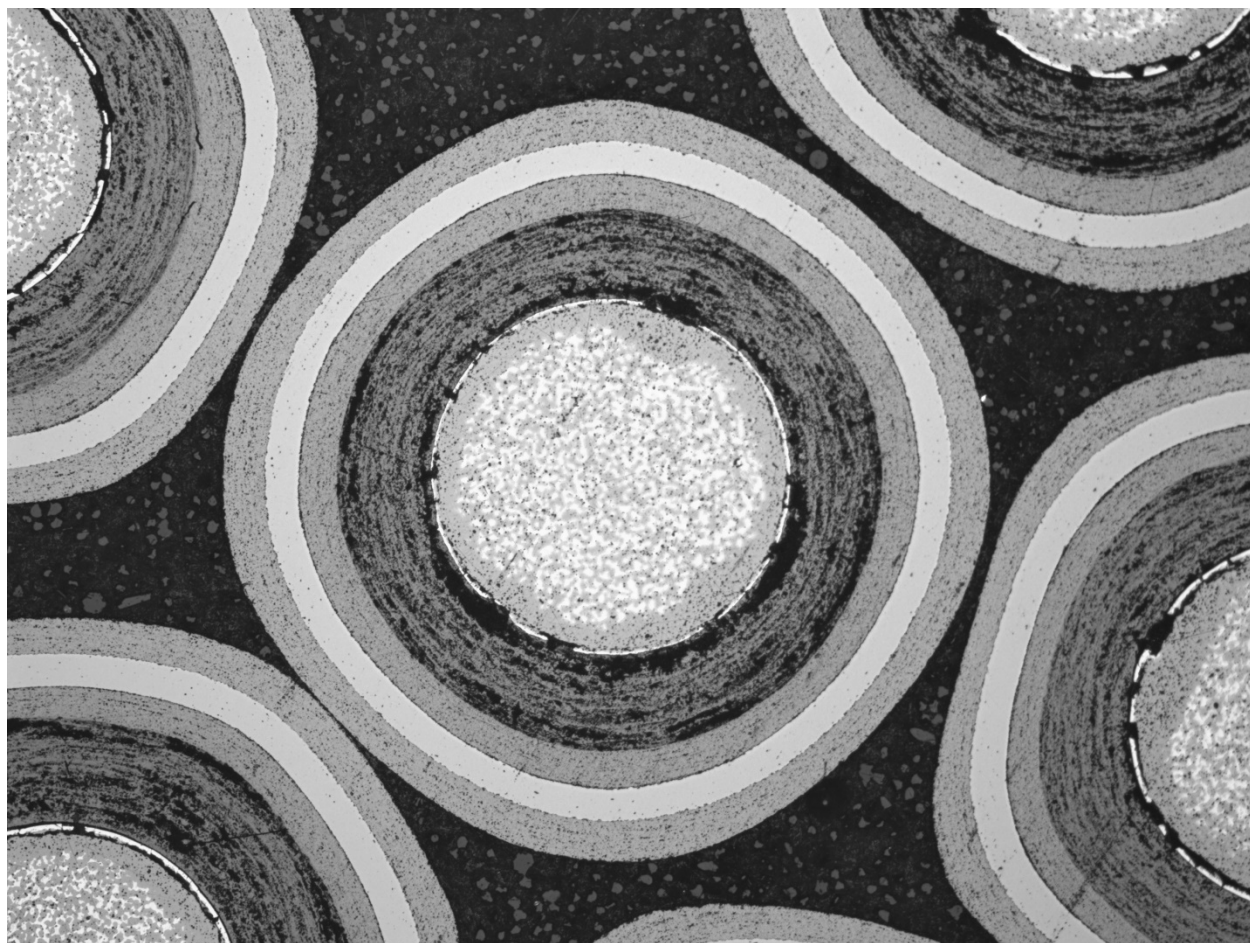


P16082301N113



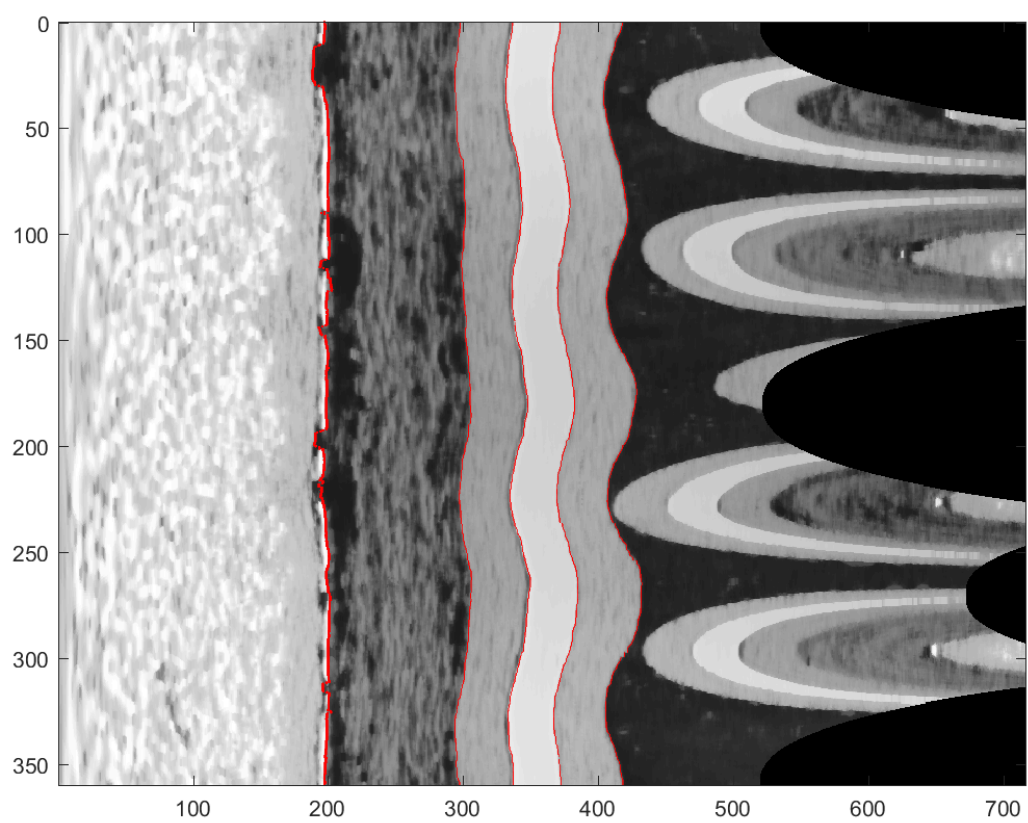
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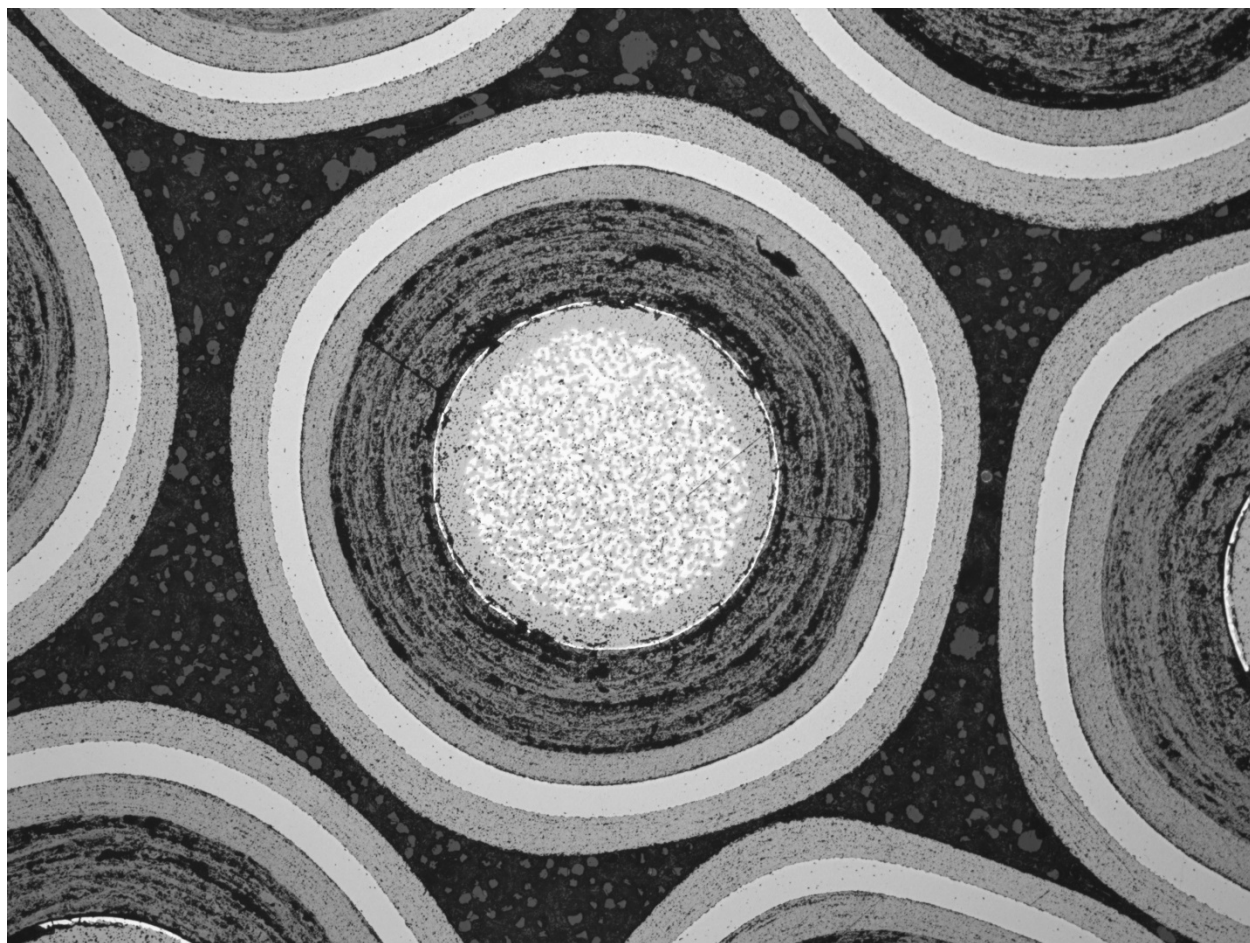


P16082301N115

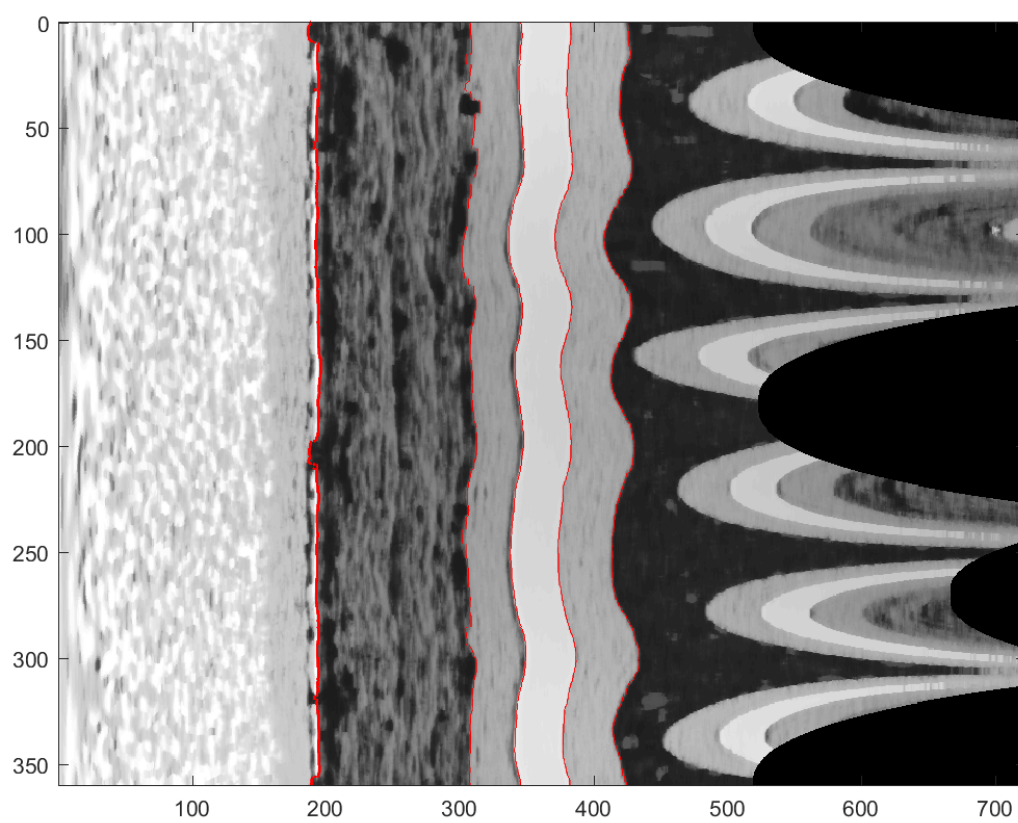




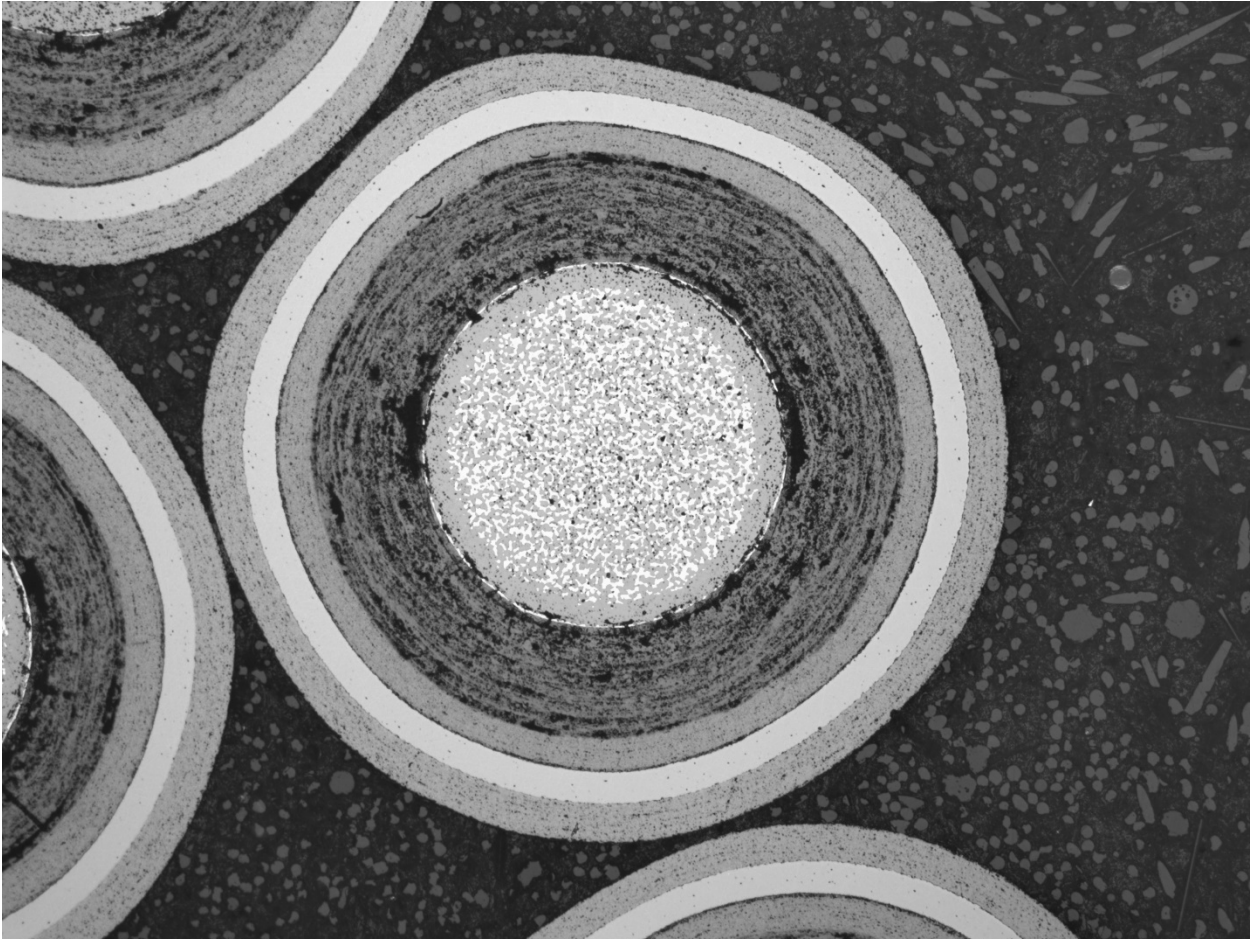
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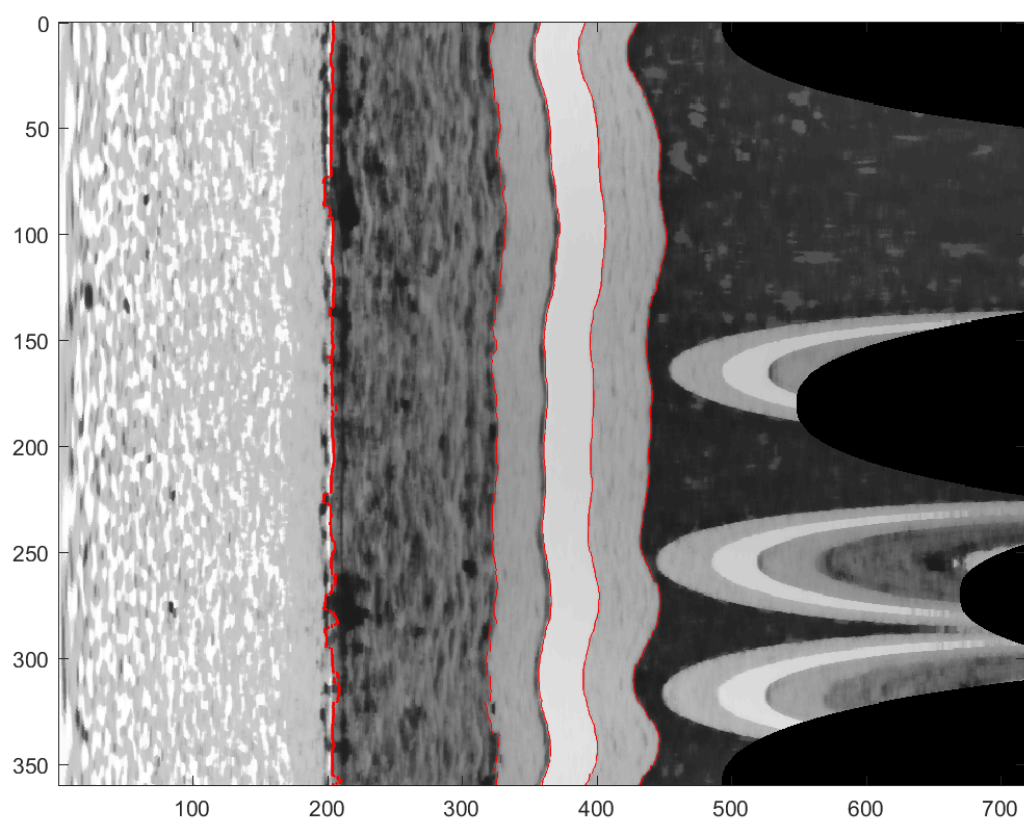
P16082301N116



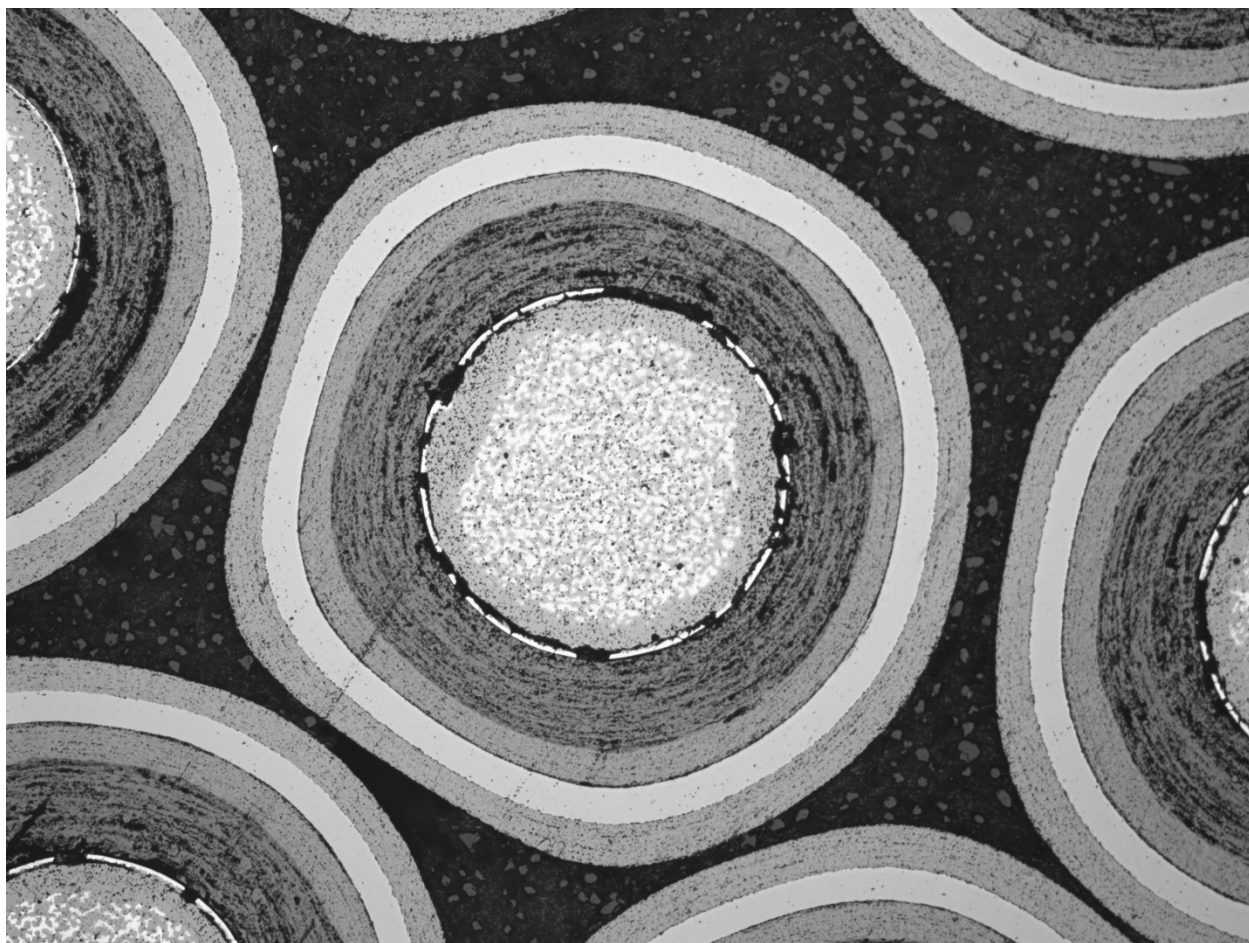
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P16082301N117

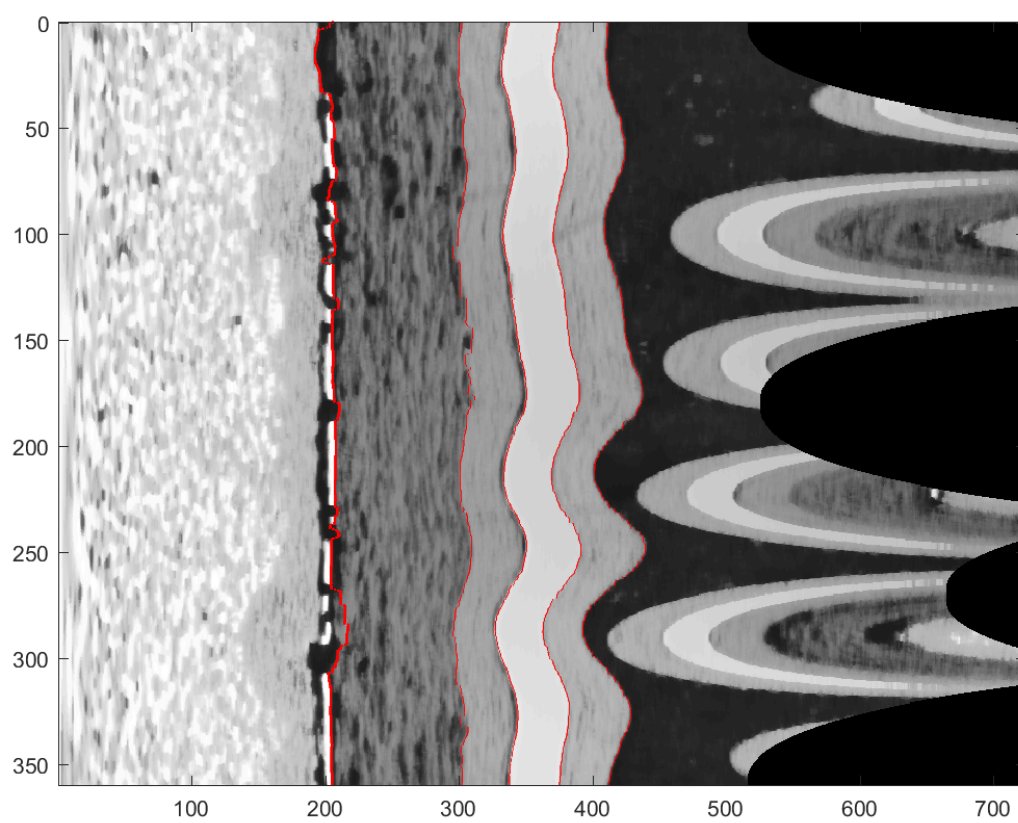


**P16082301N117 unwrapped**



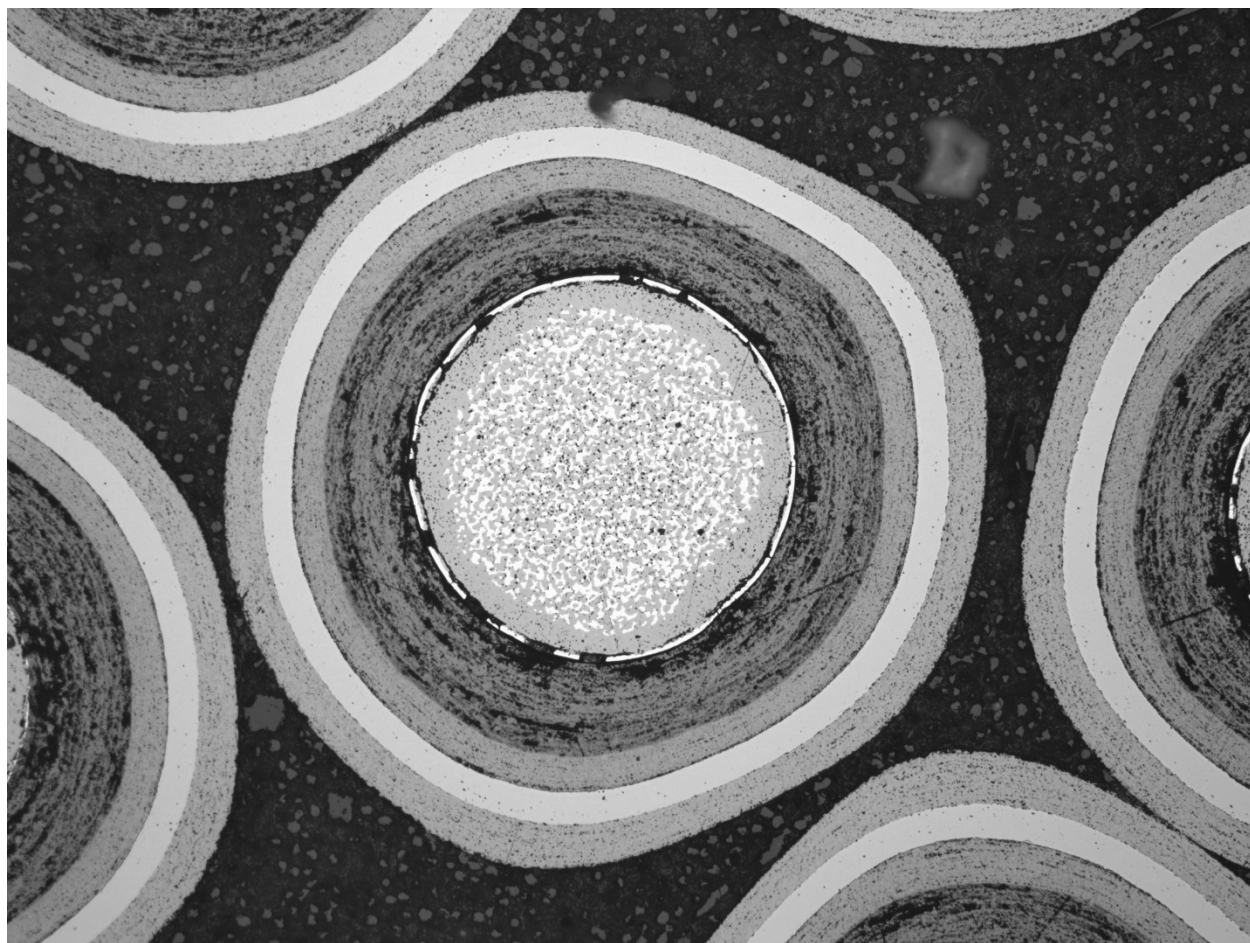
P16082301N121



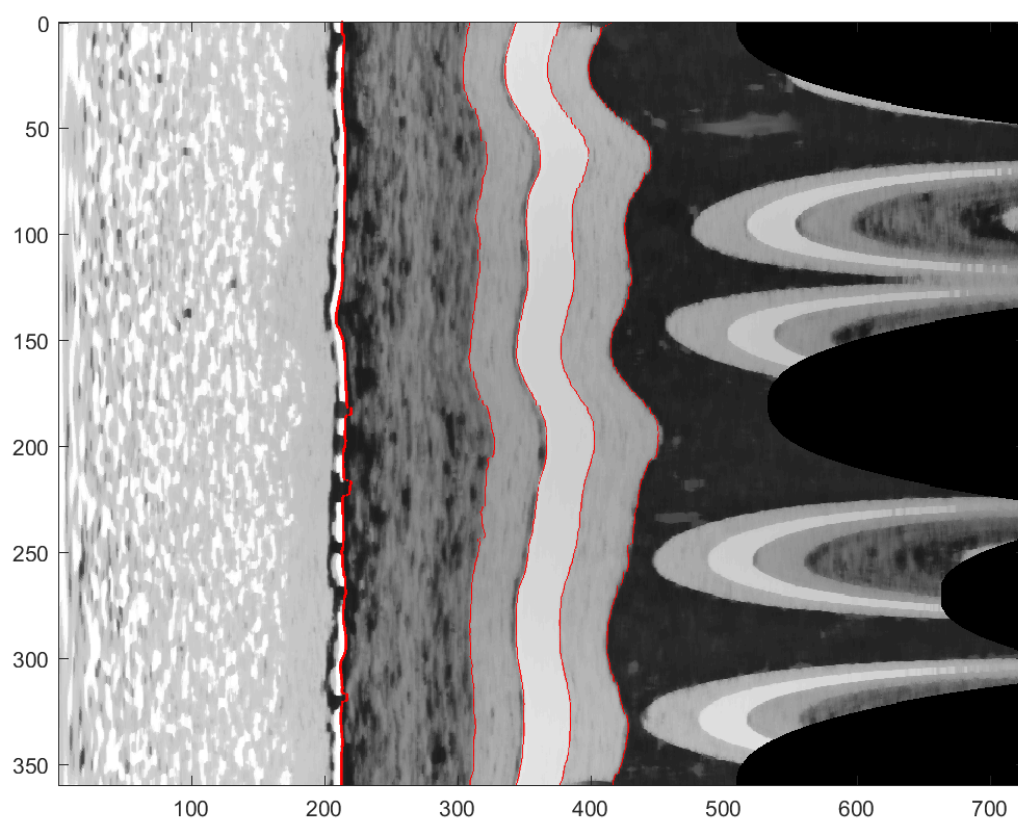


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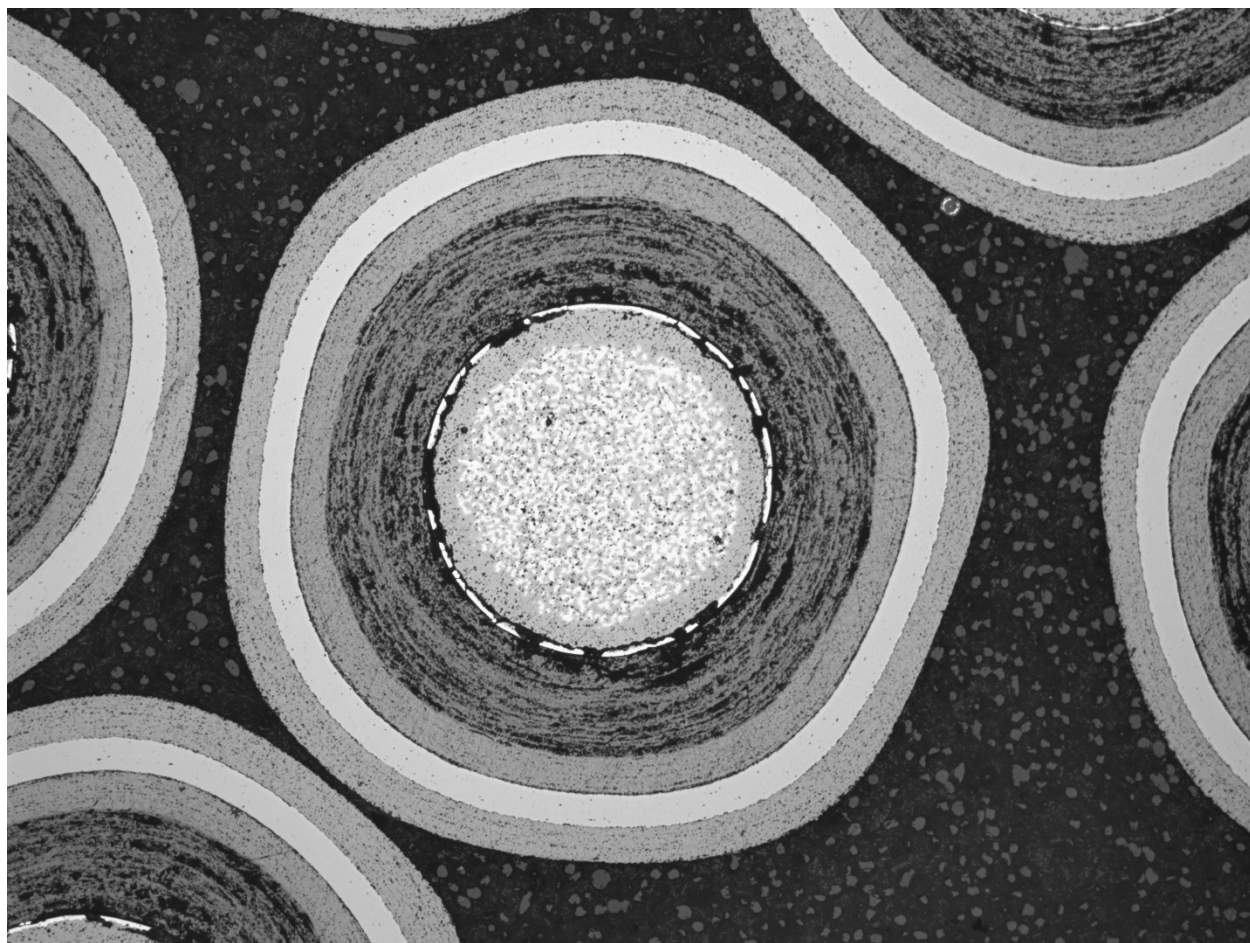




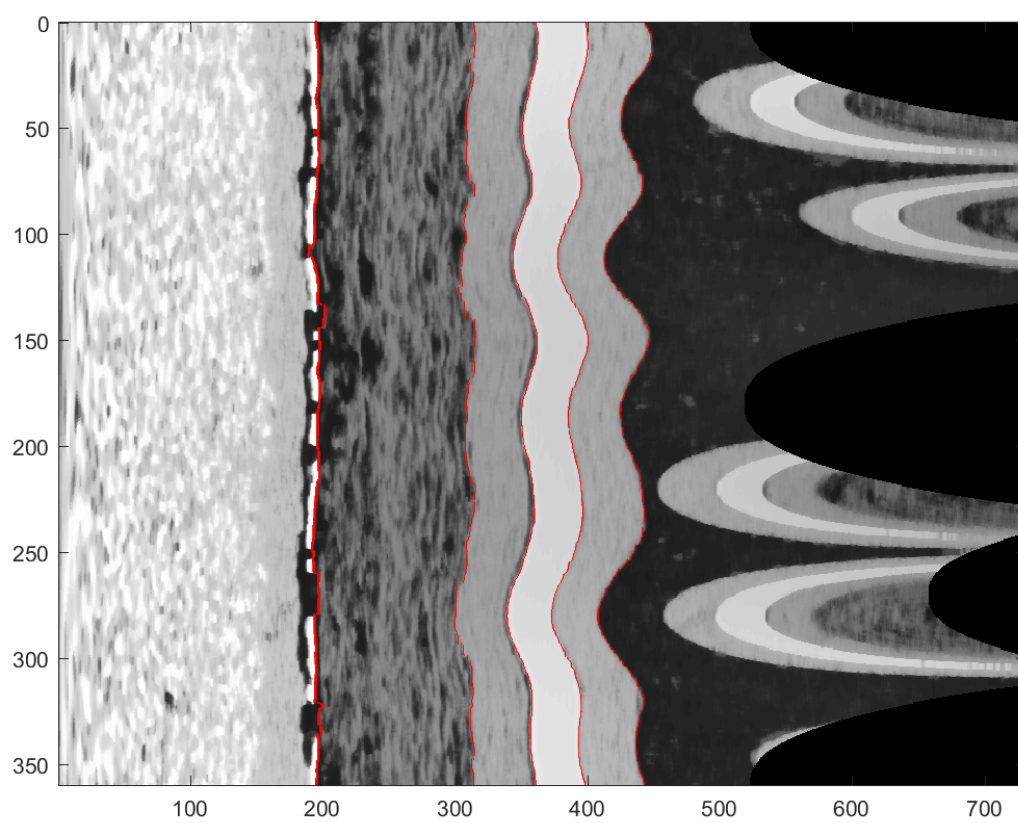
P16082301N122



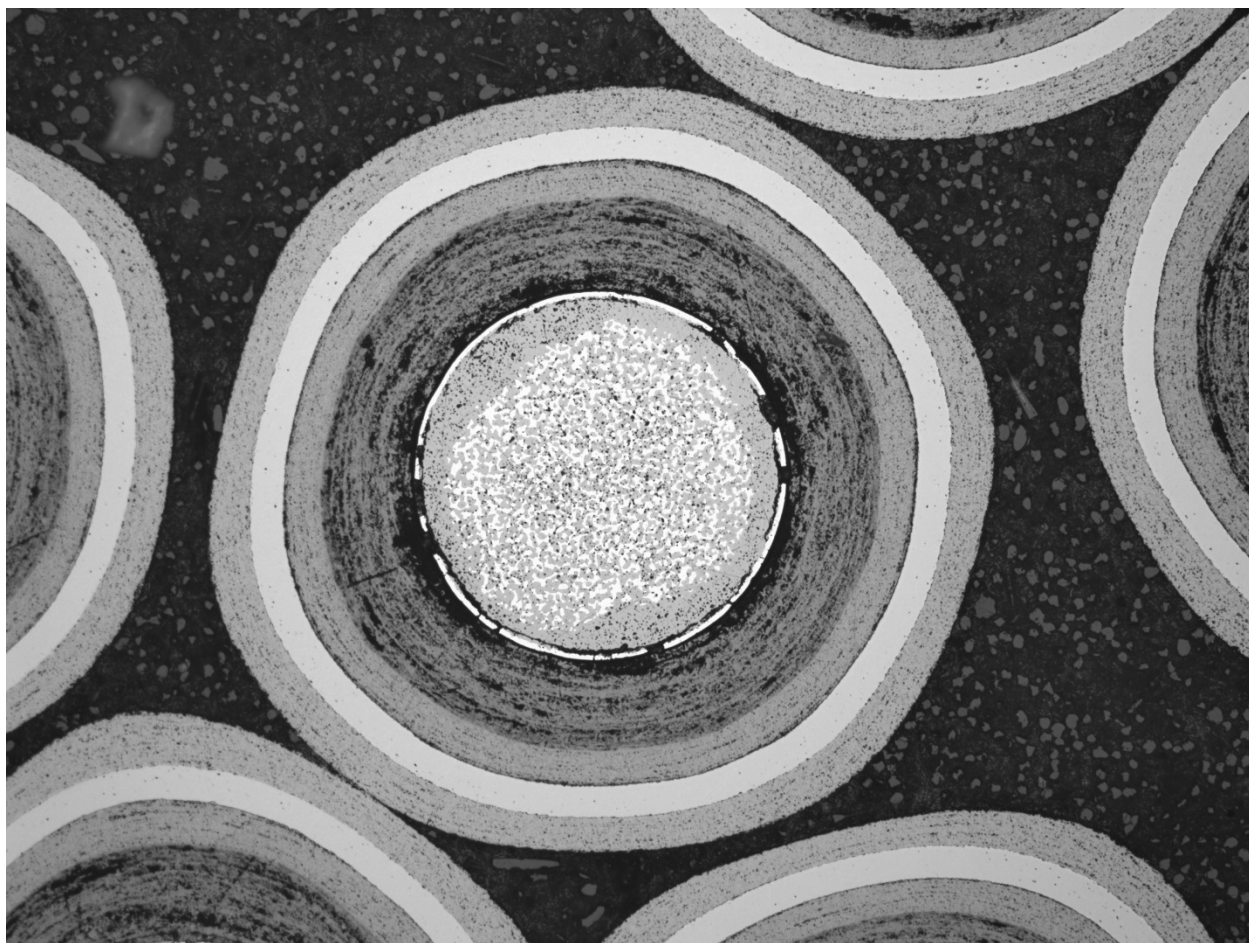
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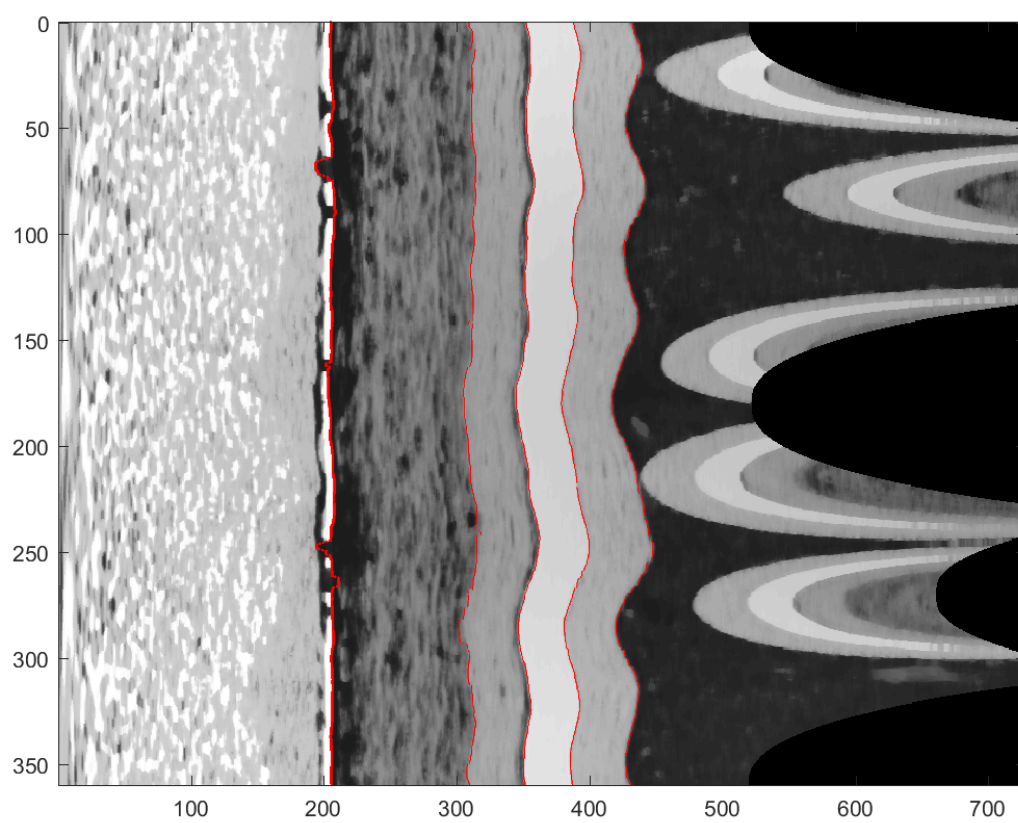
P16082301N123



**P16082301N123 unwrapped**

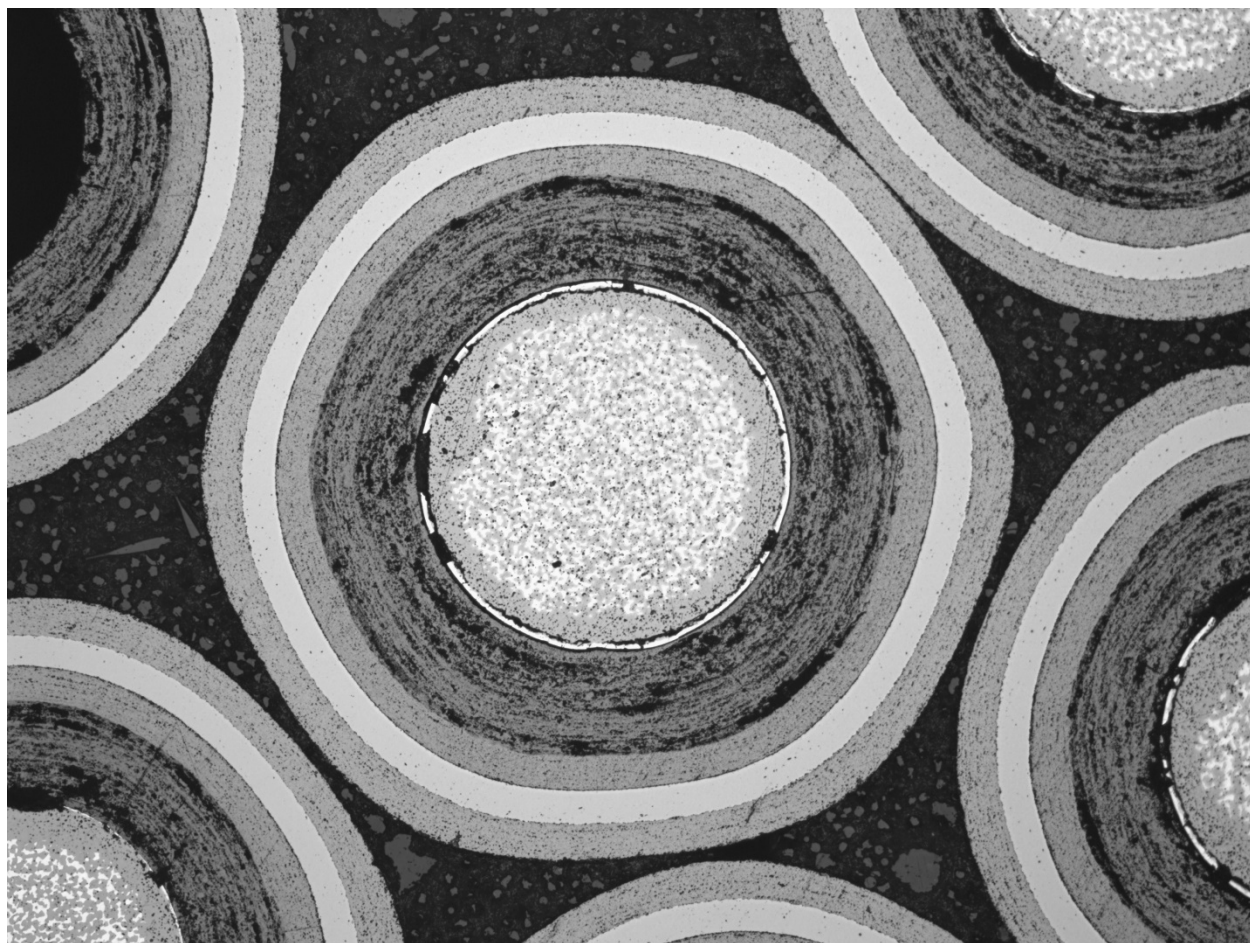


P16082301N124



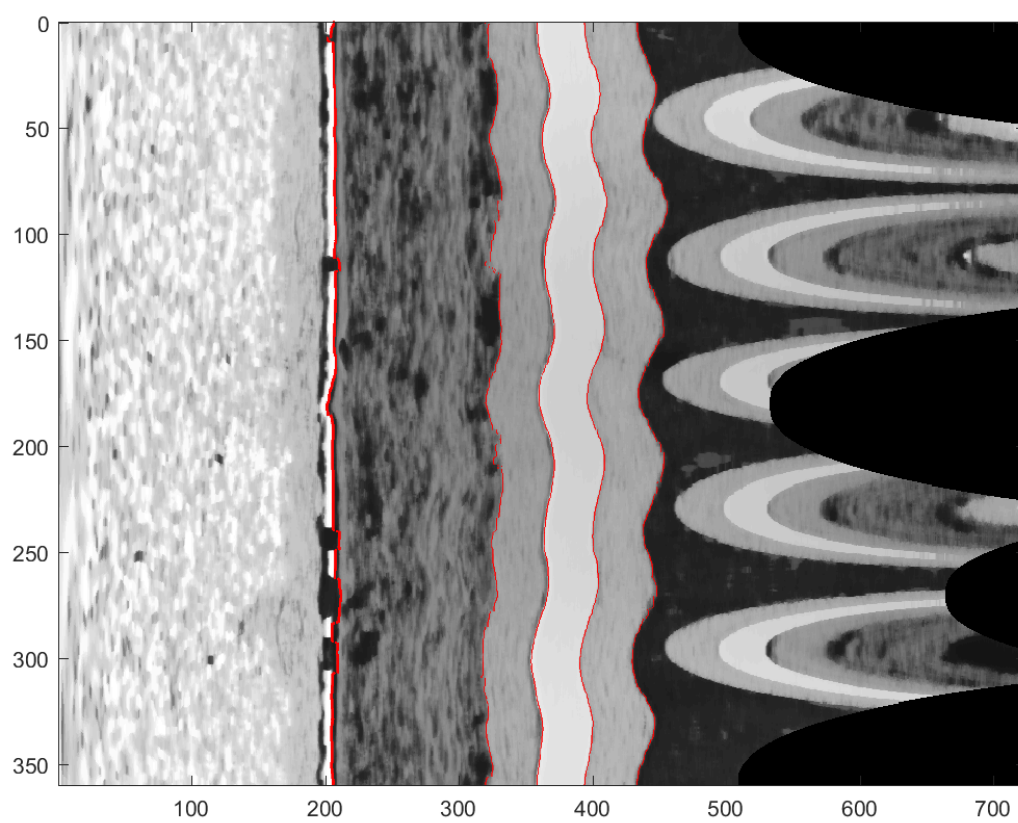
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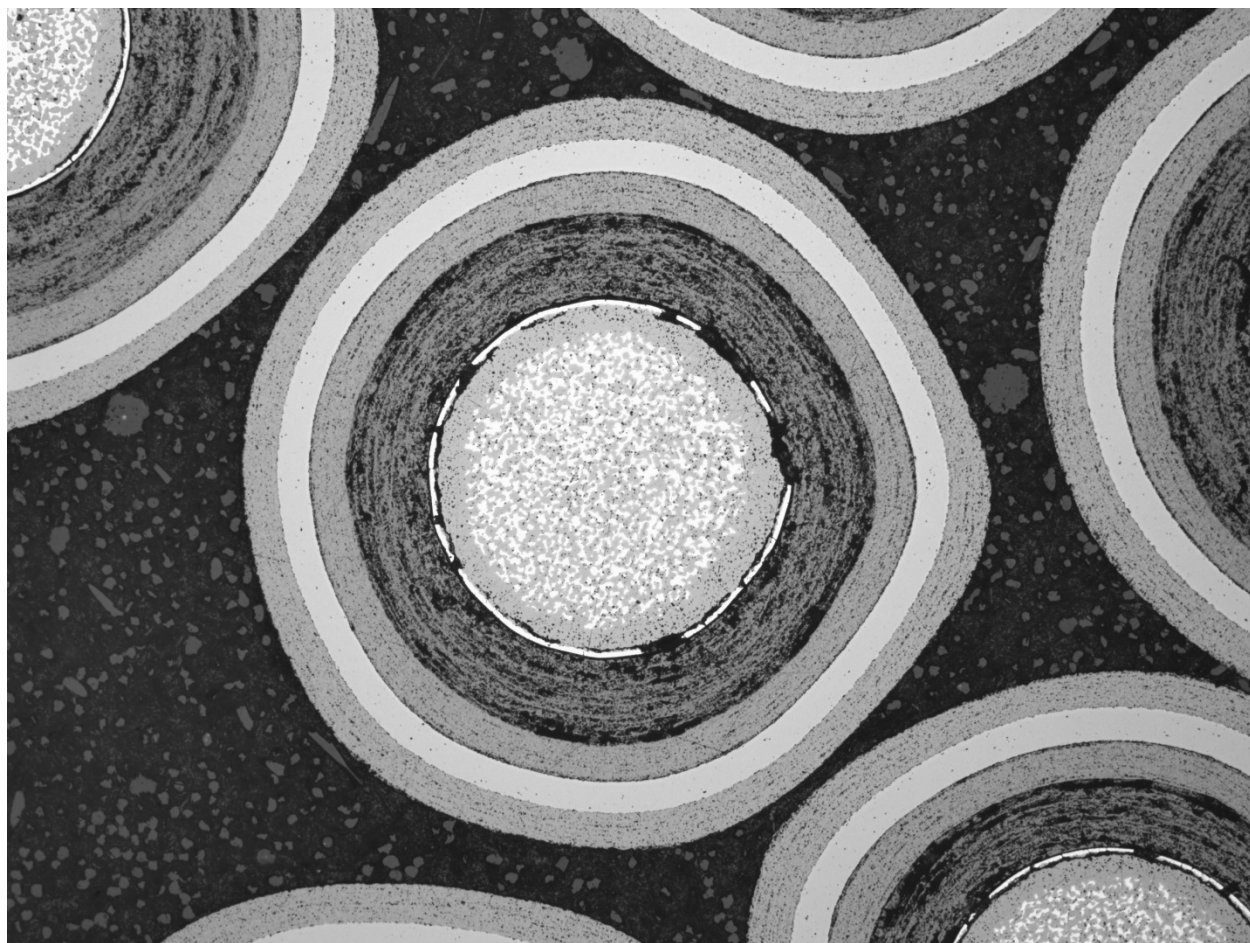


P16082301N128

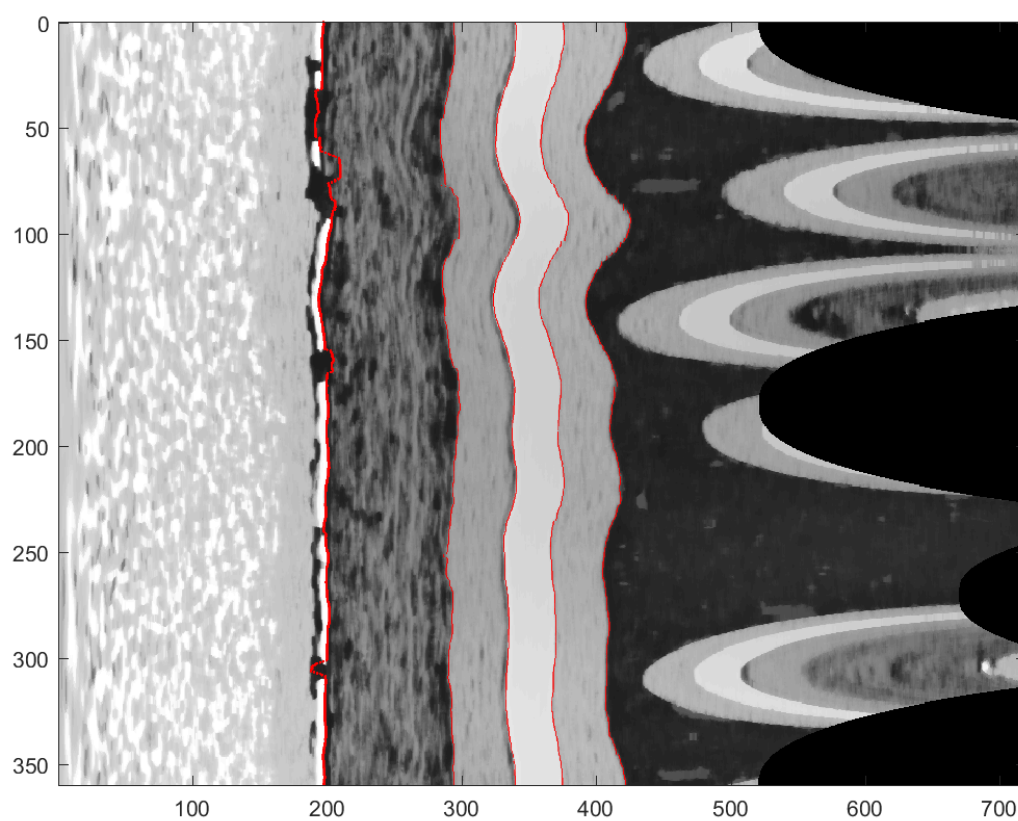




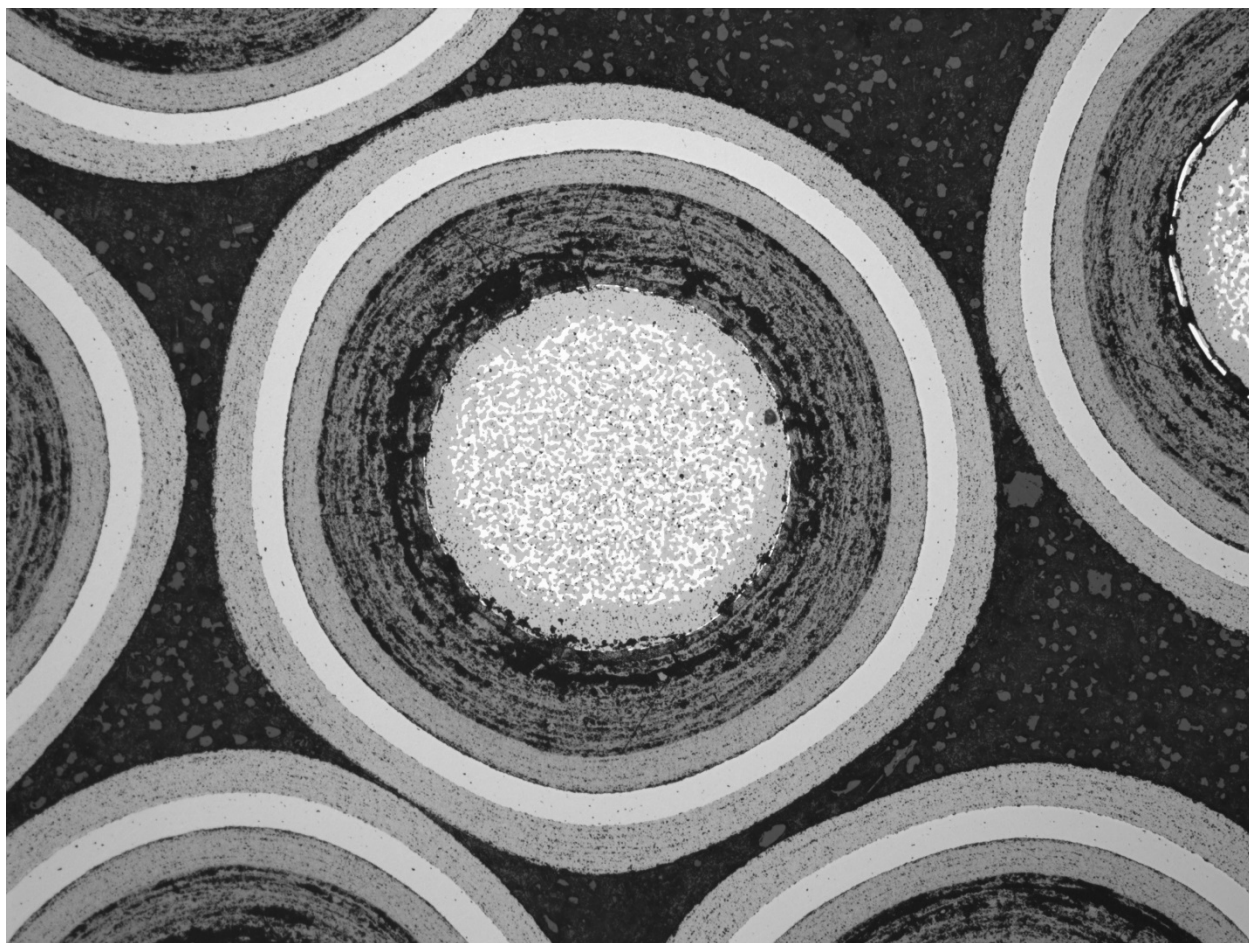
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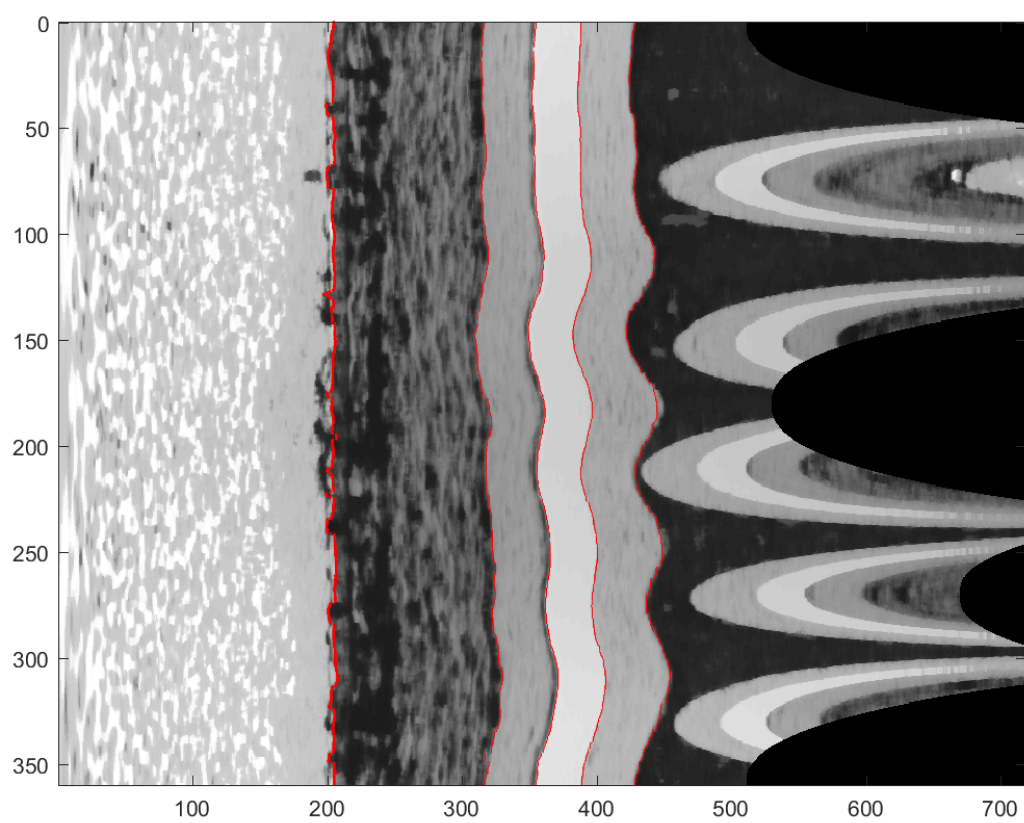
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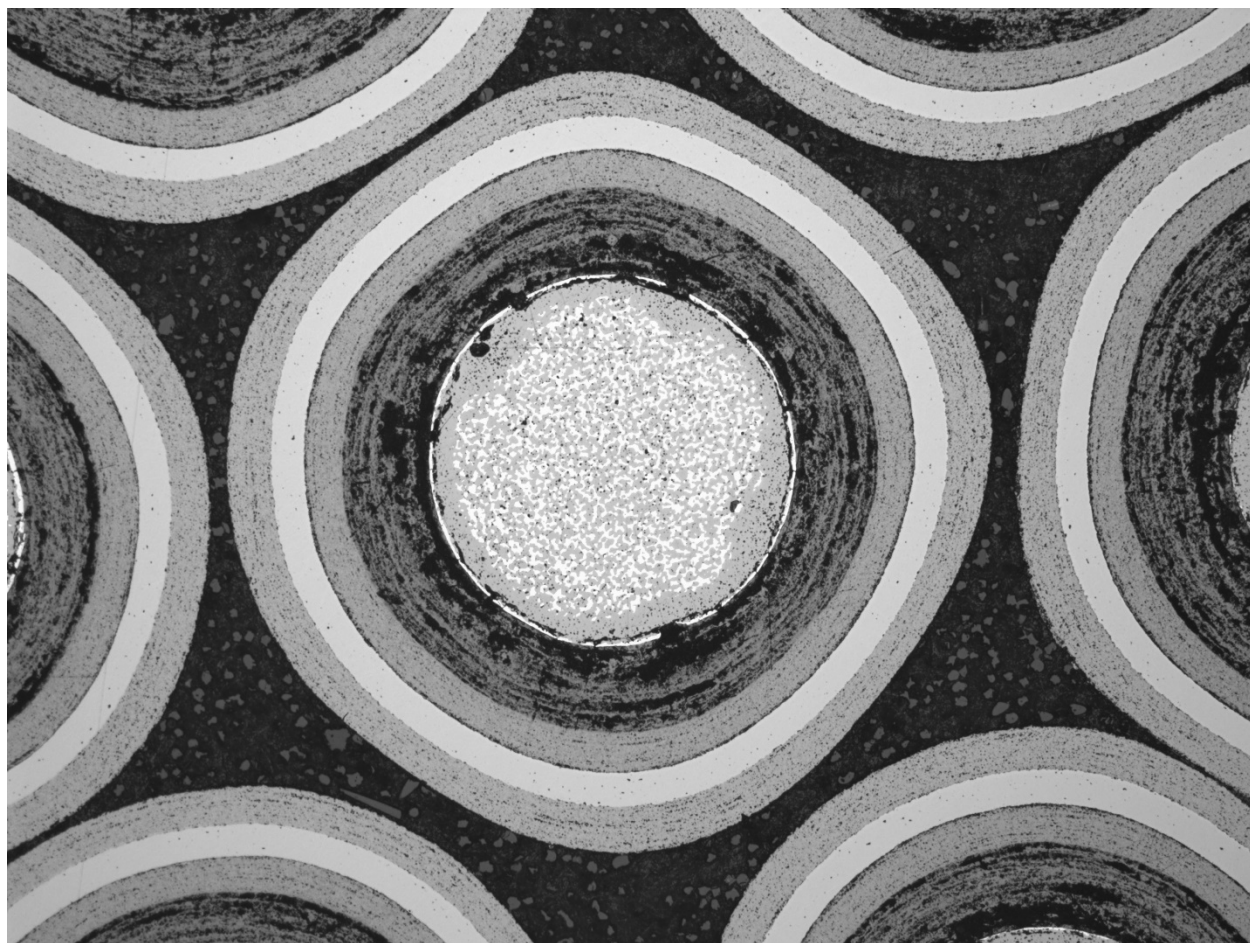
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P16082301N130

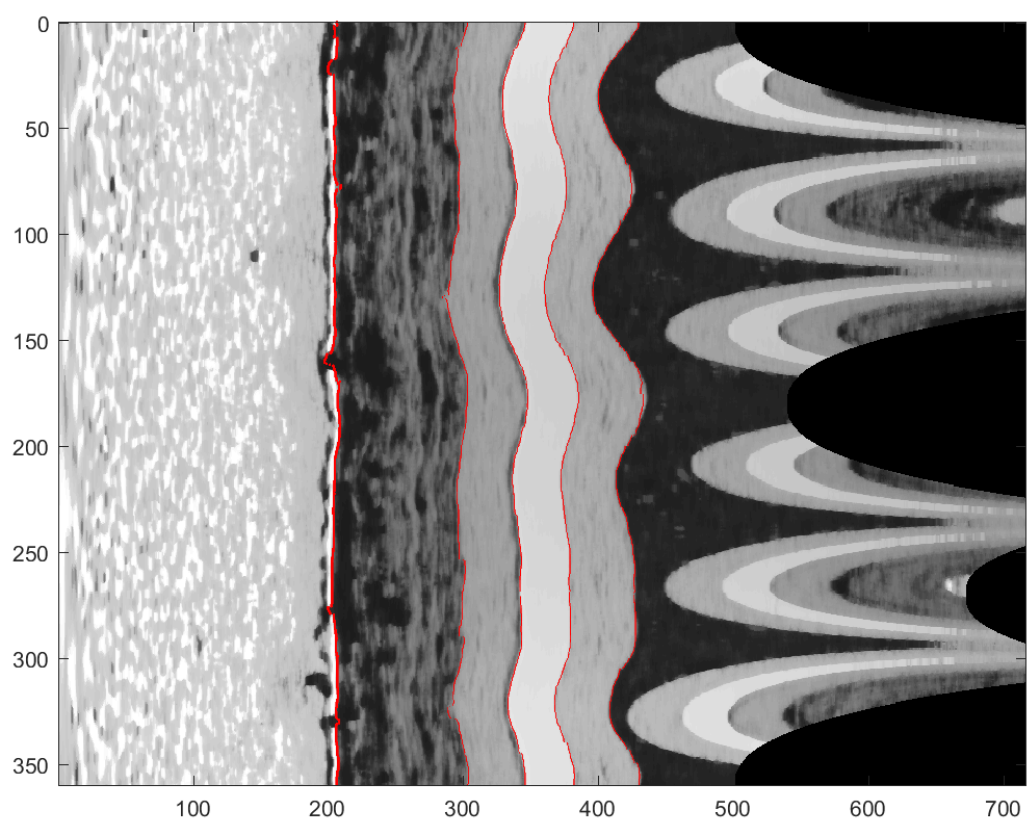


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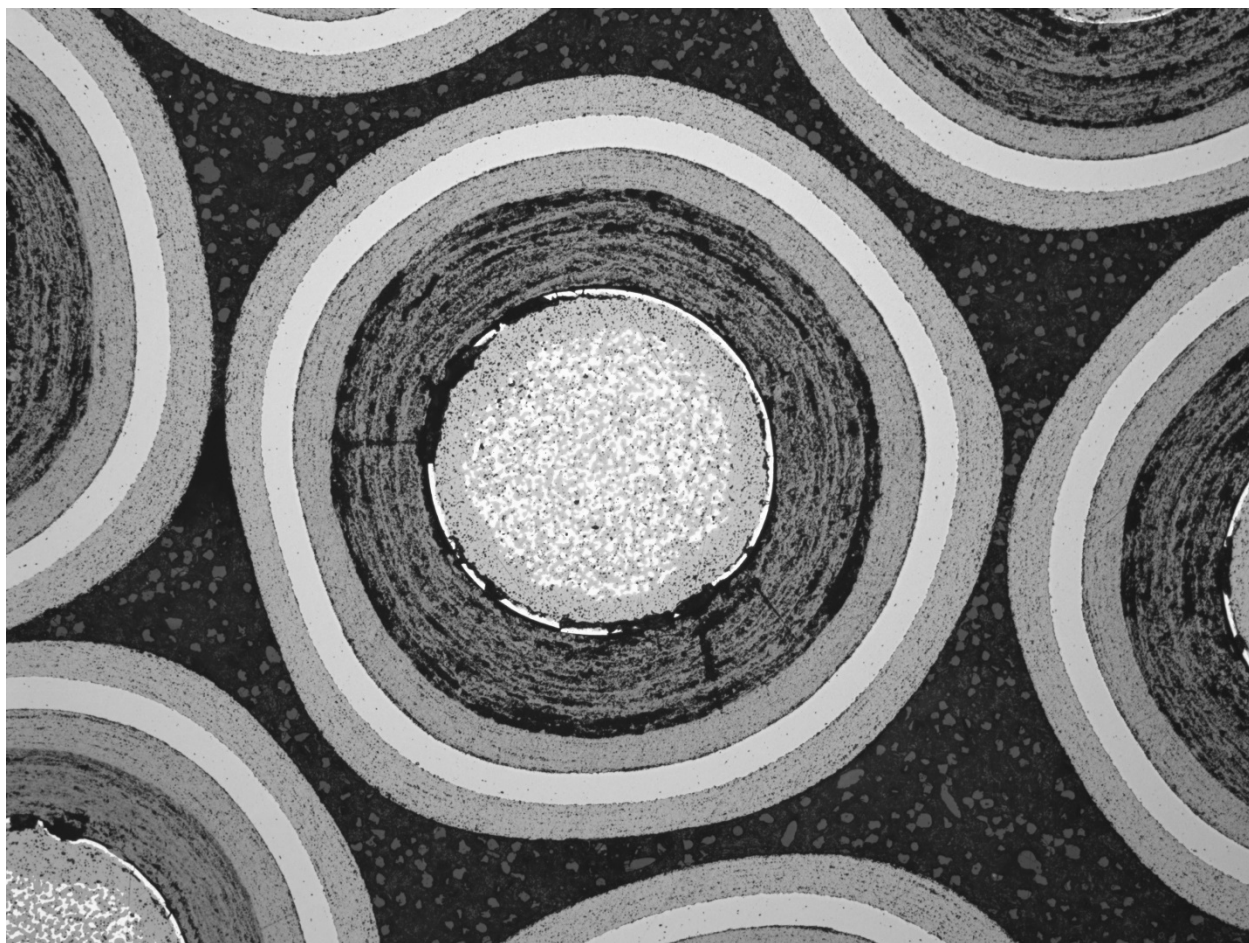
P16082301N131



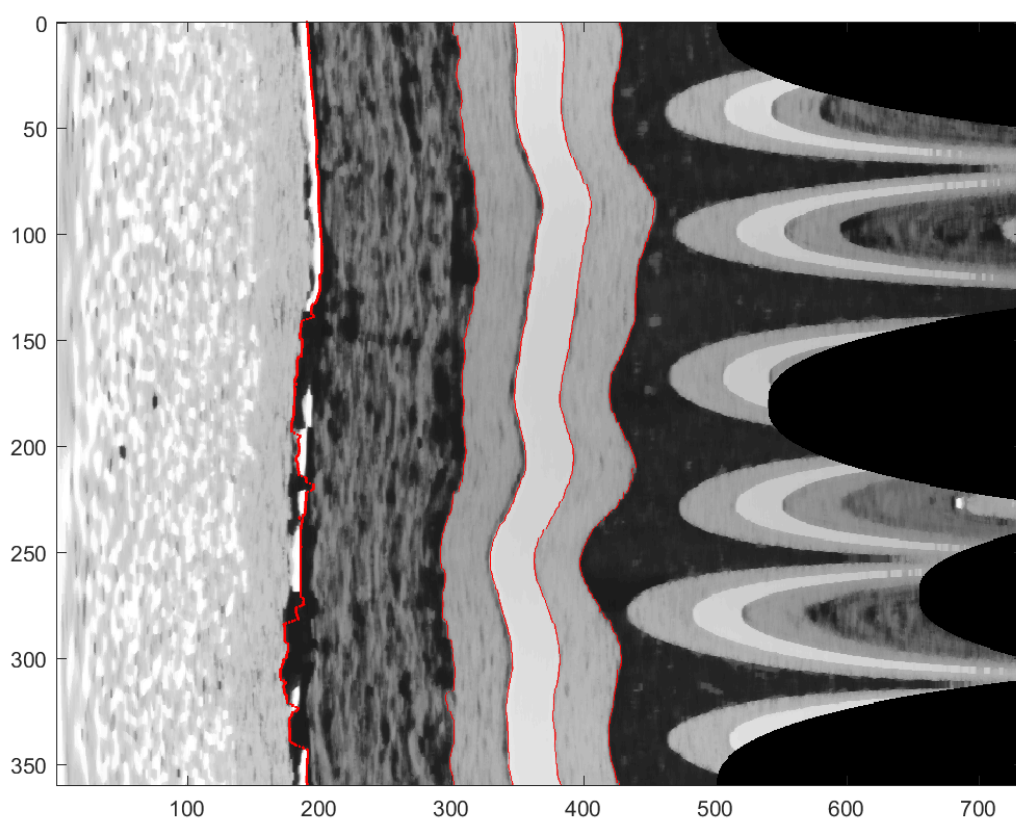


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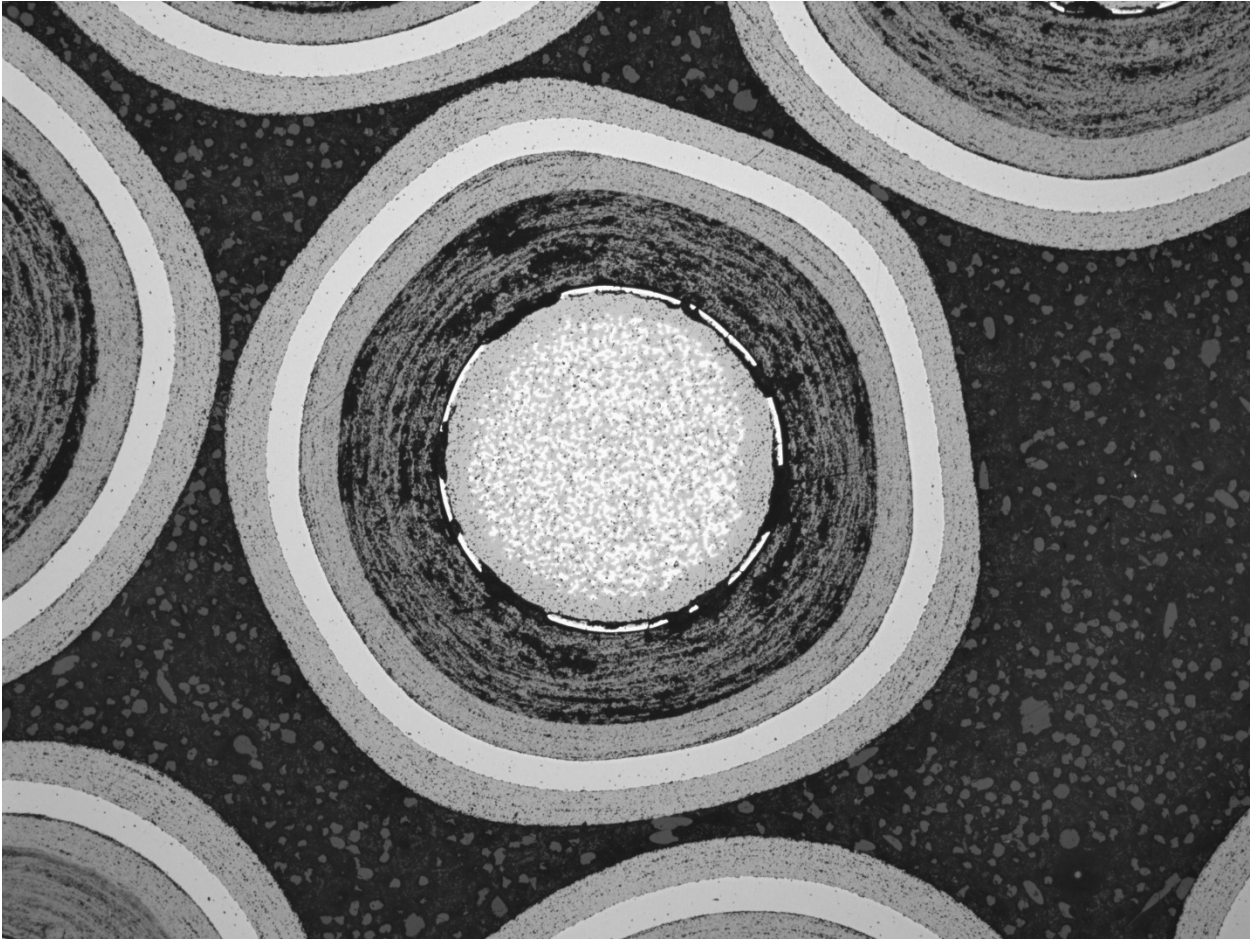




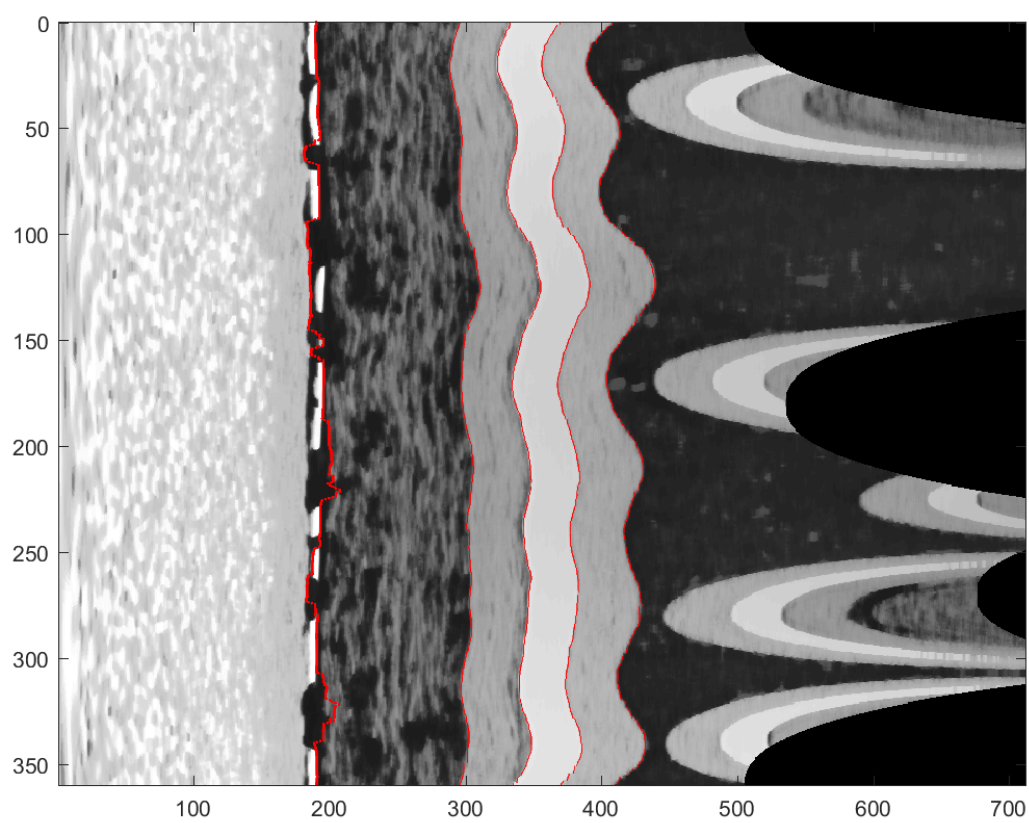
P16082301N133



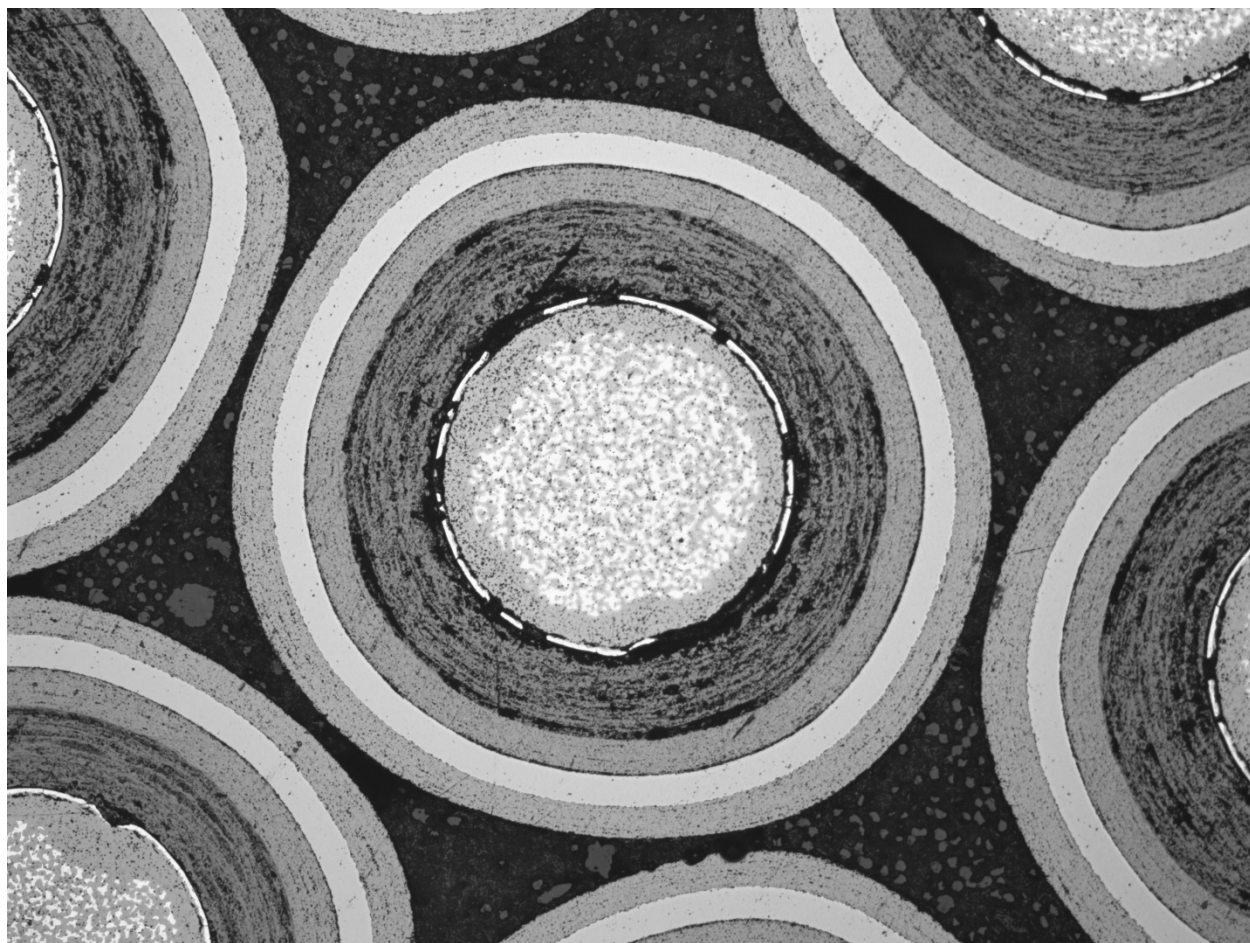
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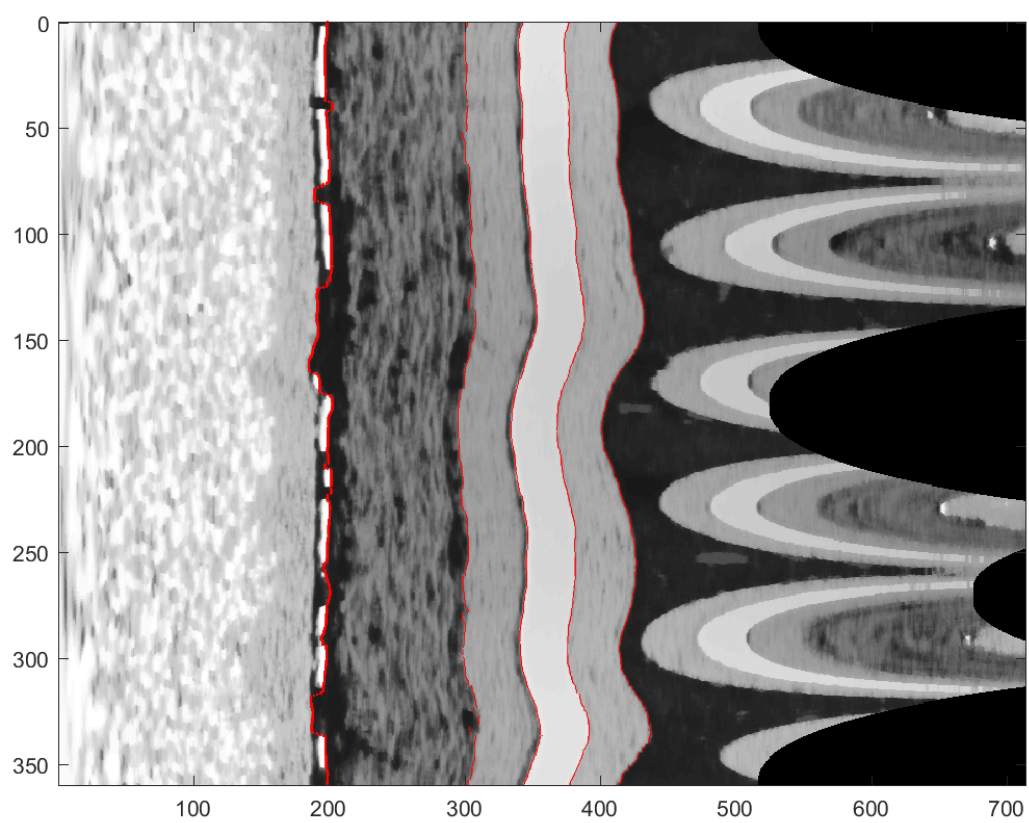
P16082301N136



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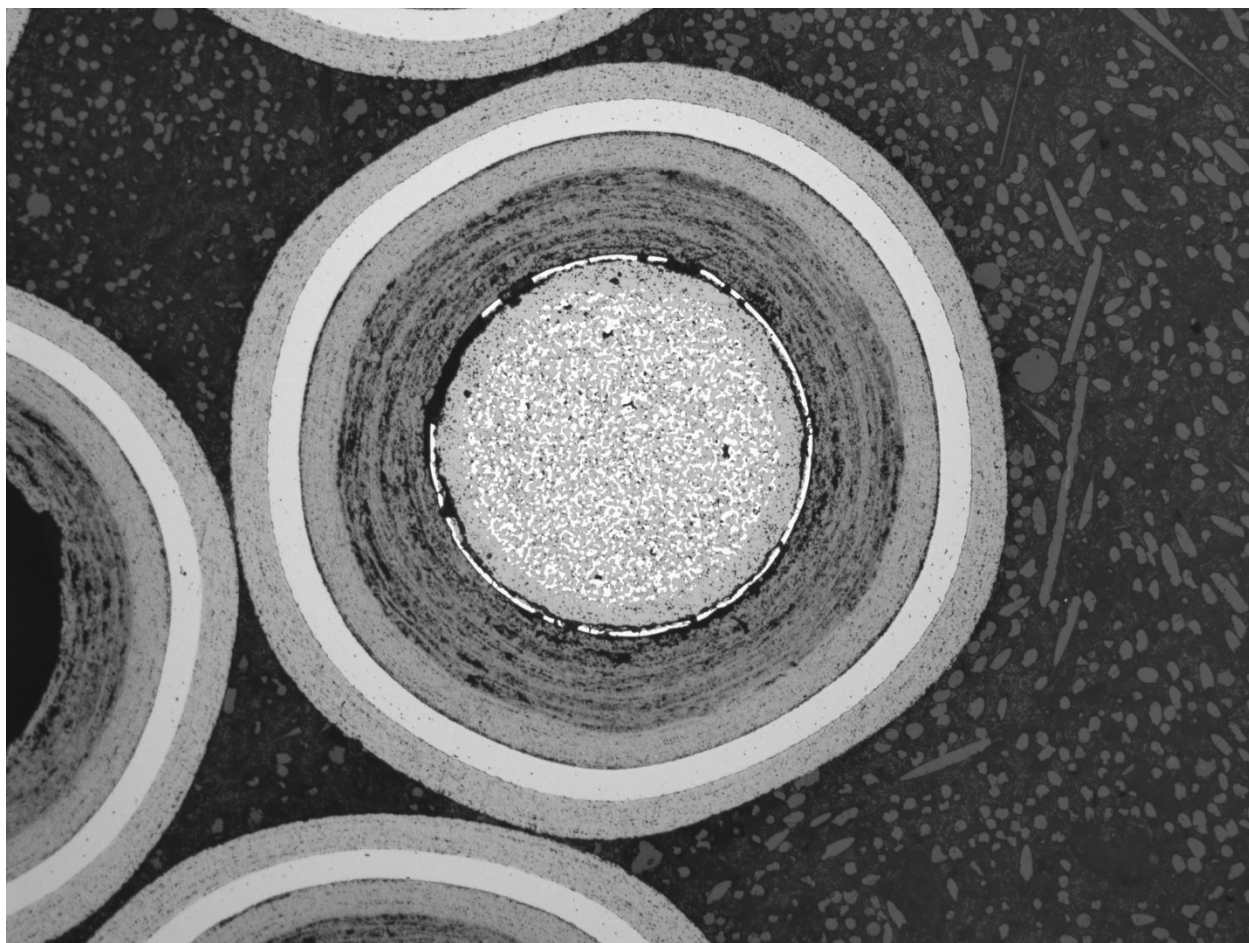


P16082301N137



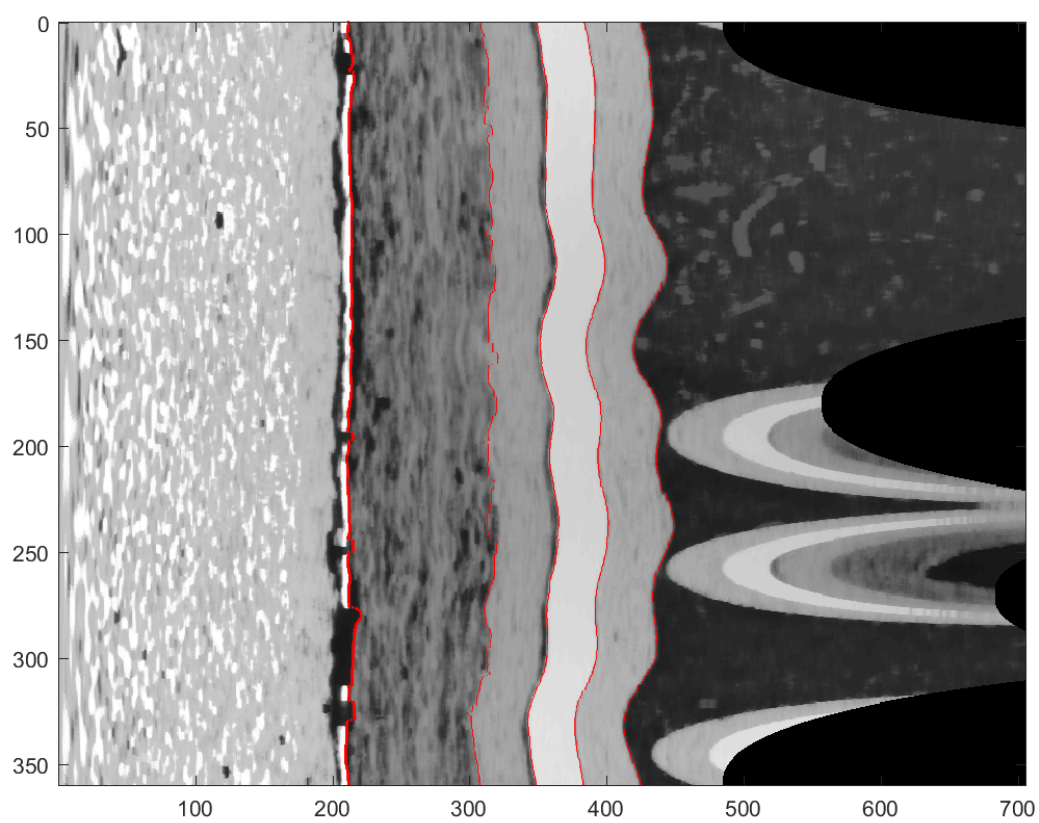
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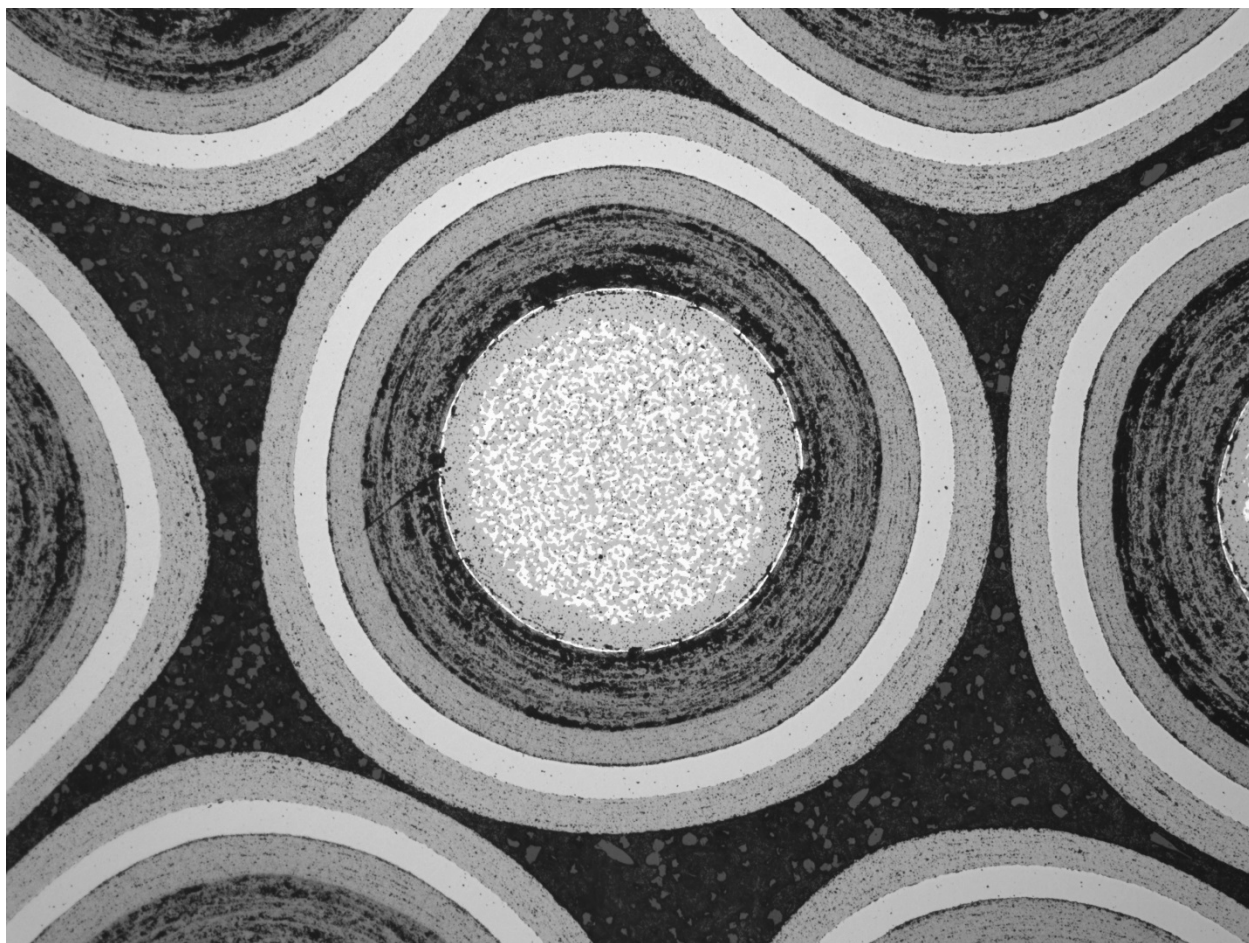


P16082301N138

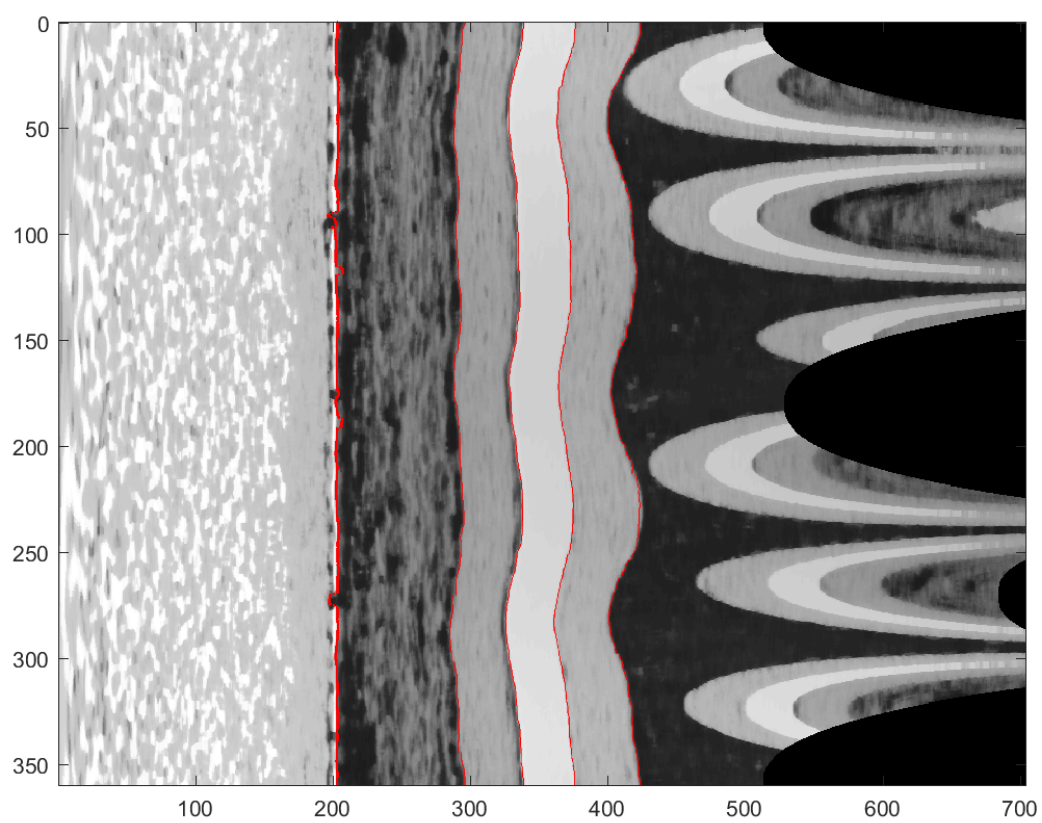




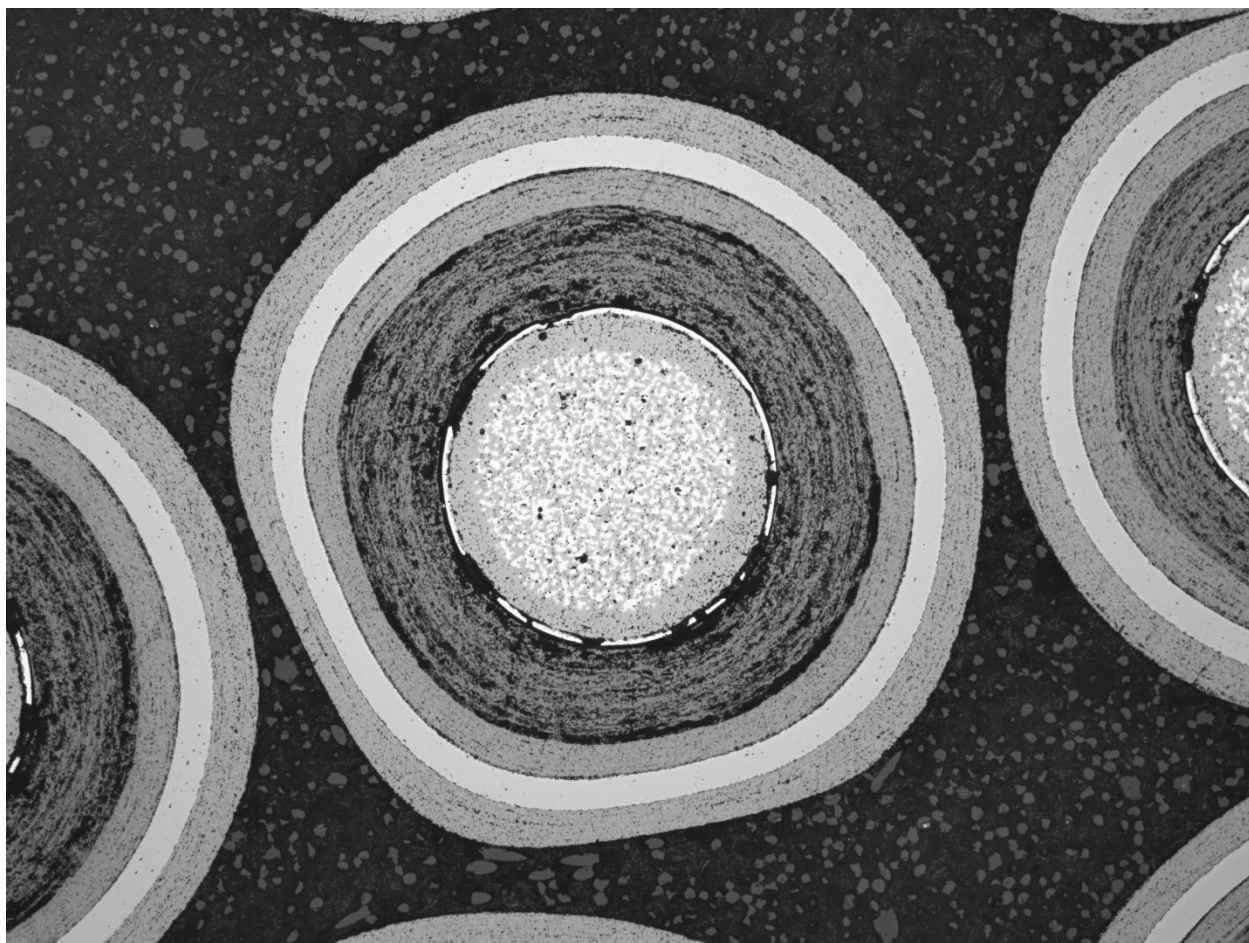
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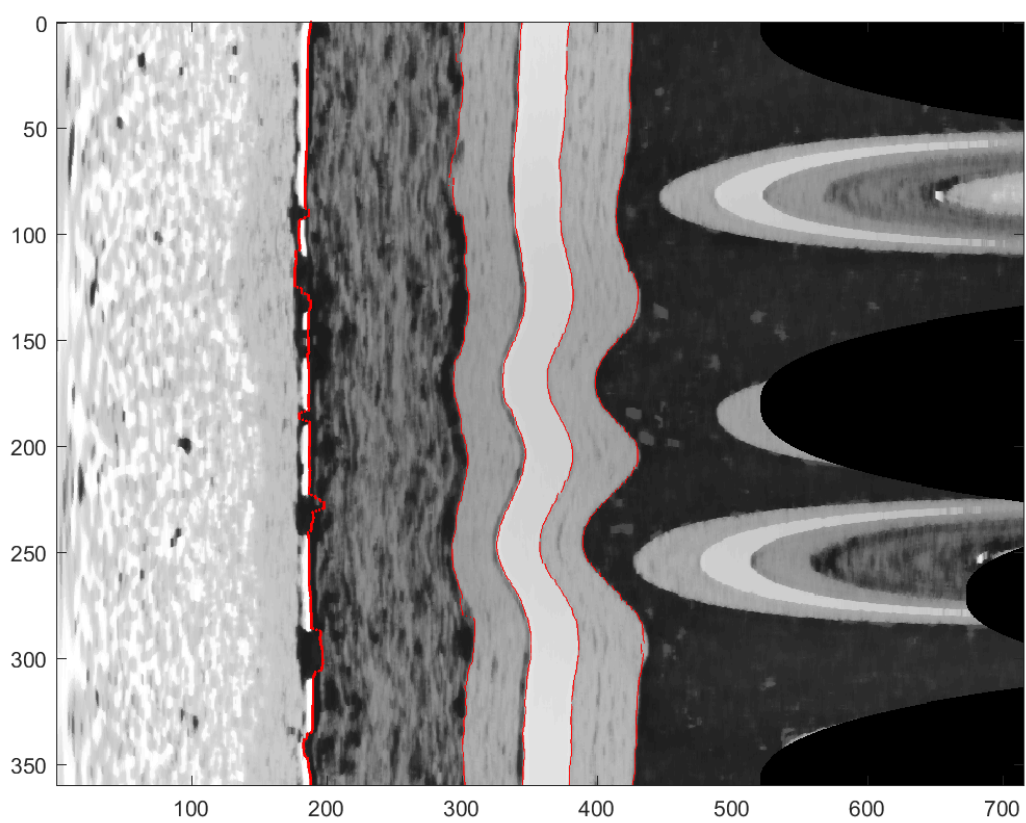
P16082301N145



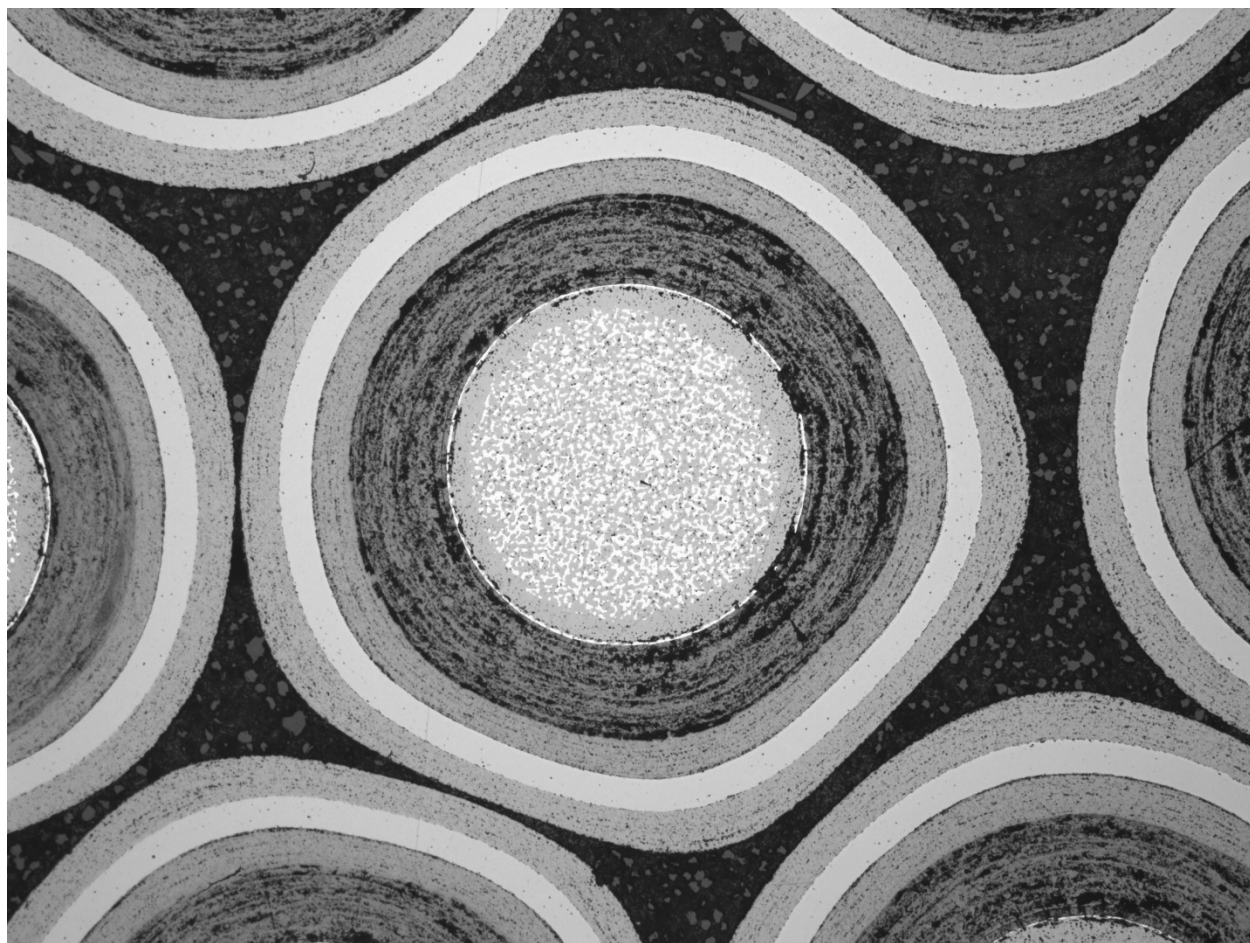
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P16082301N147

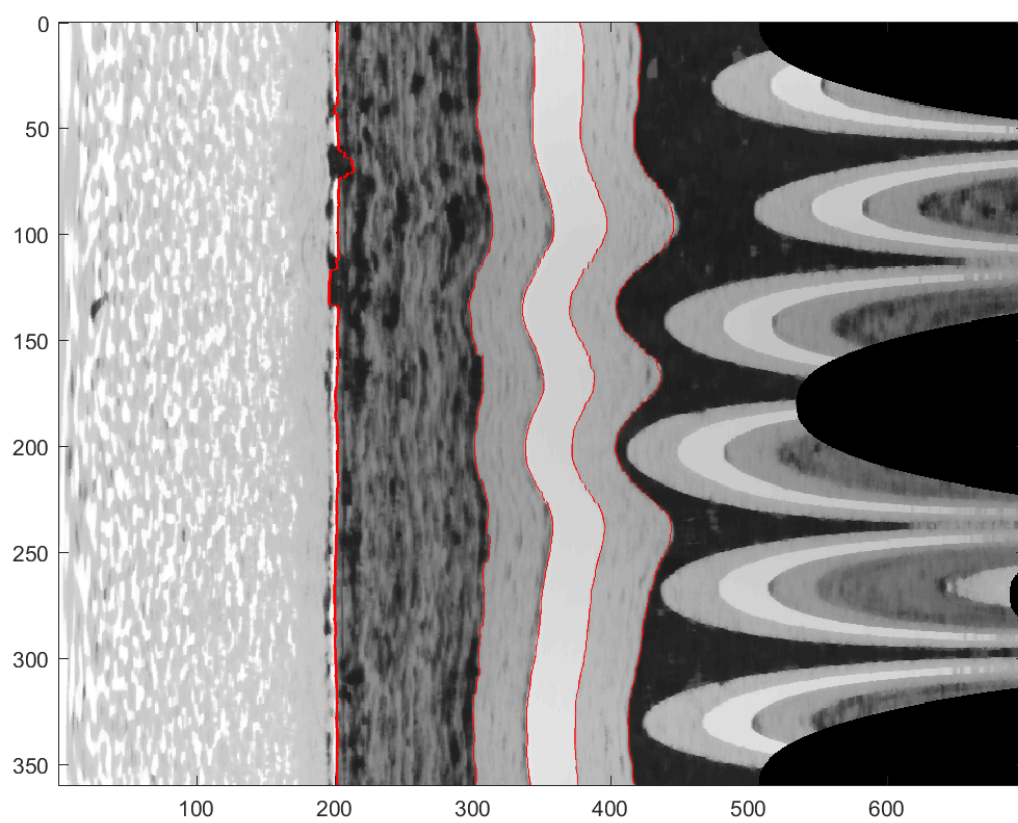


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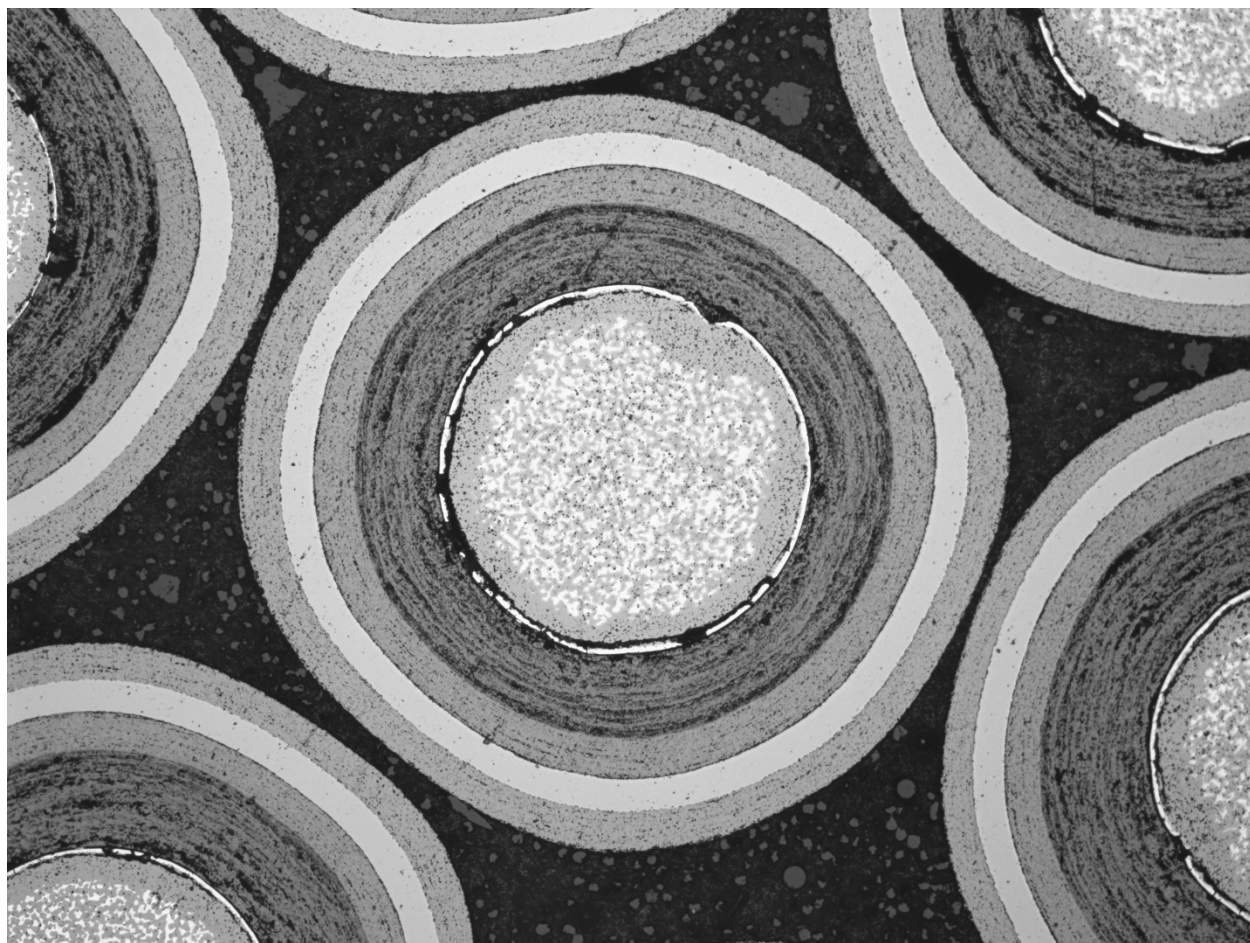
P16082301N148



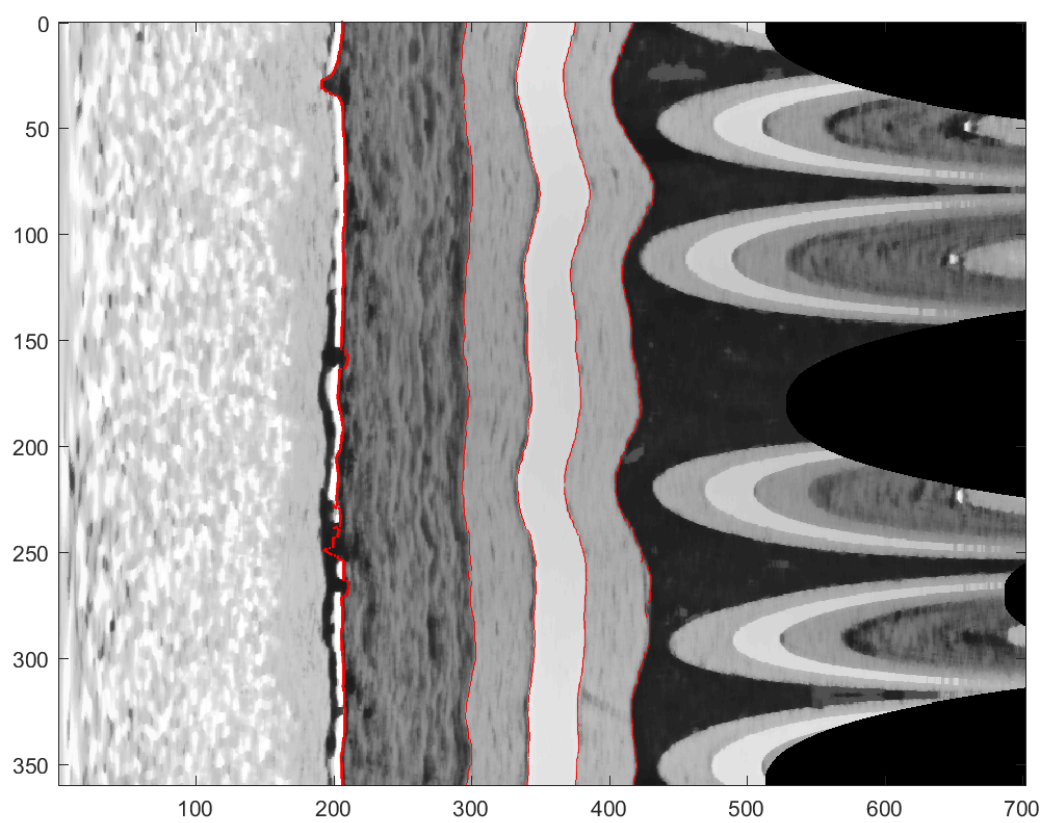


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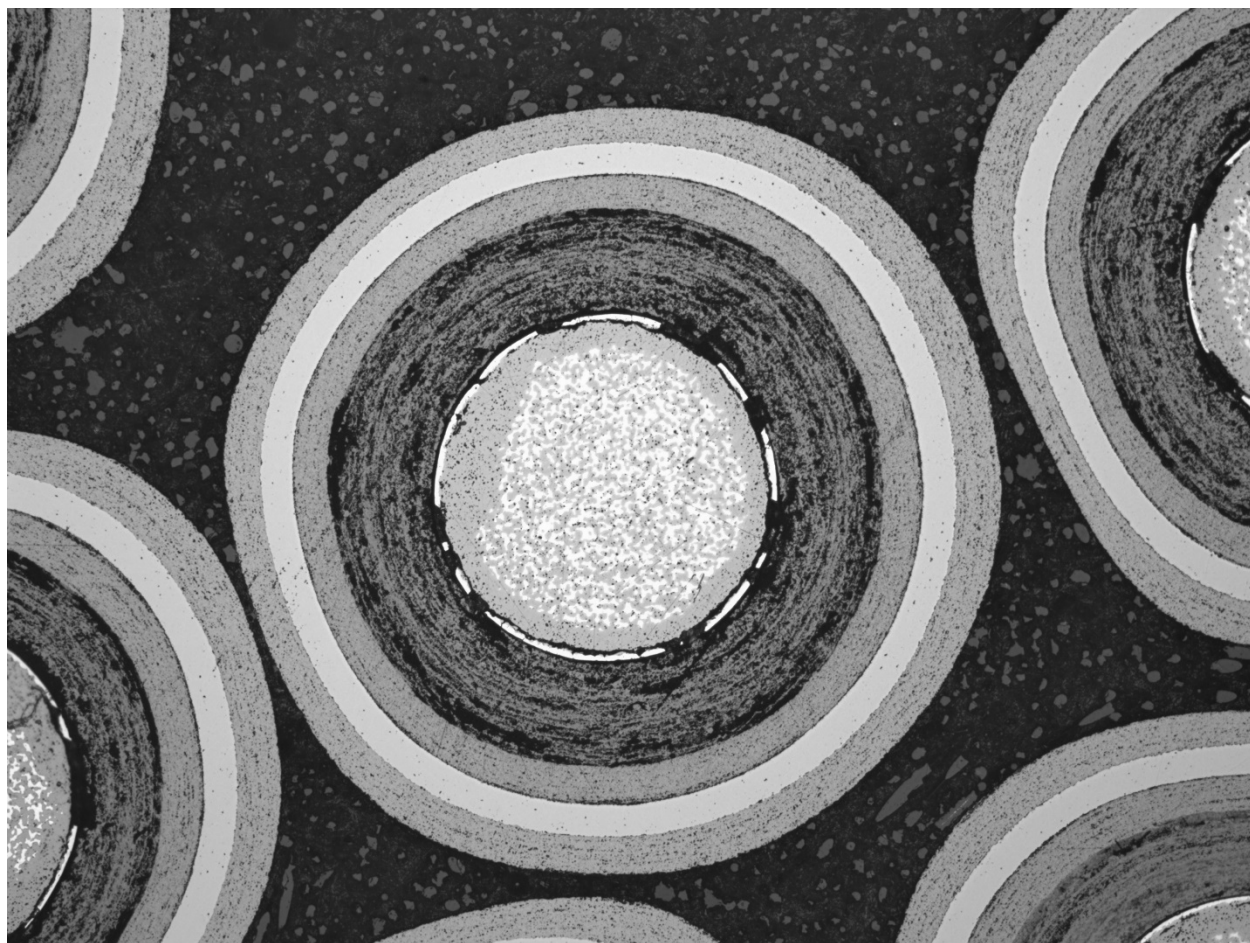




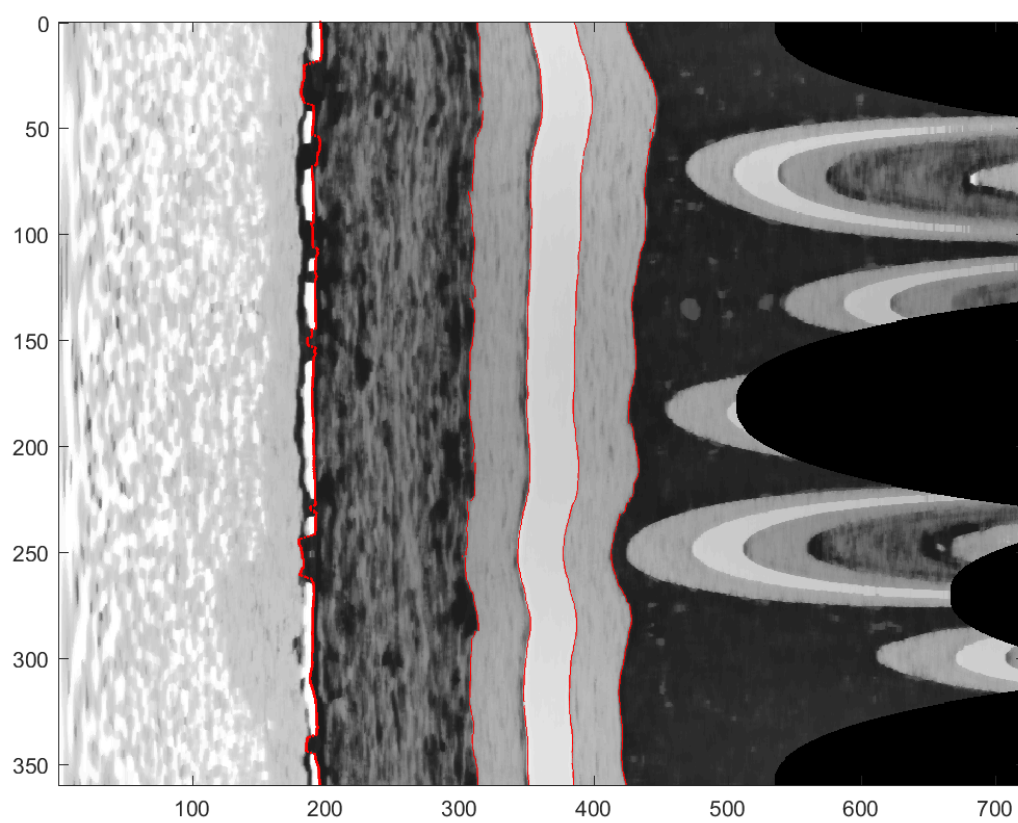
P16082301N149



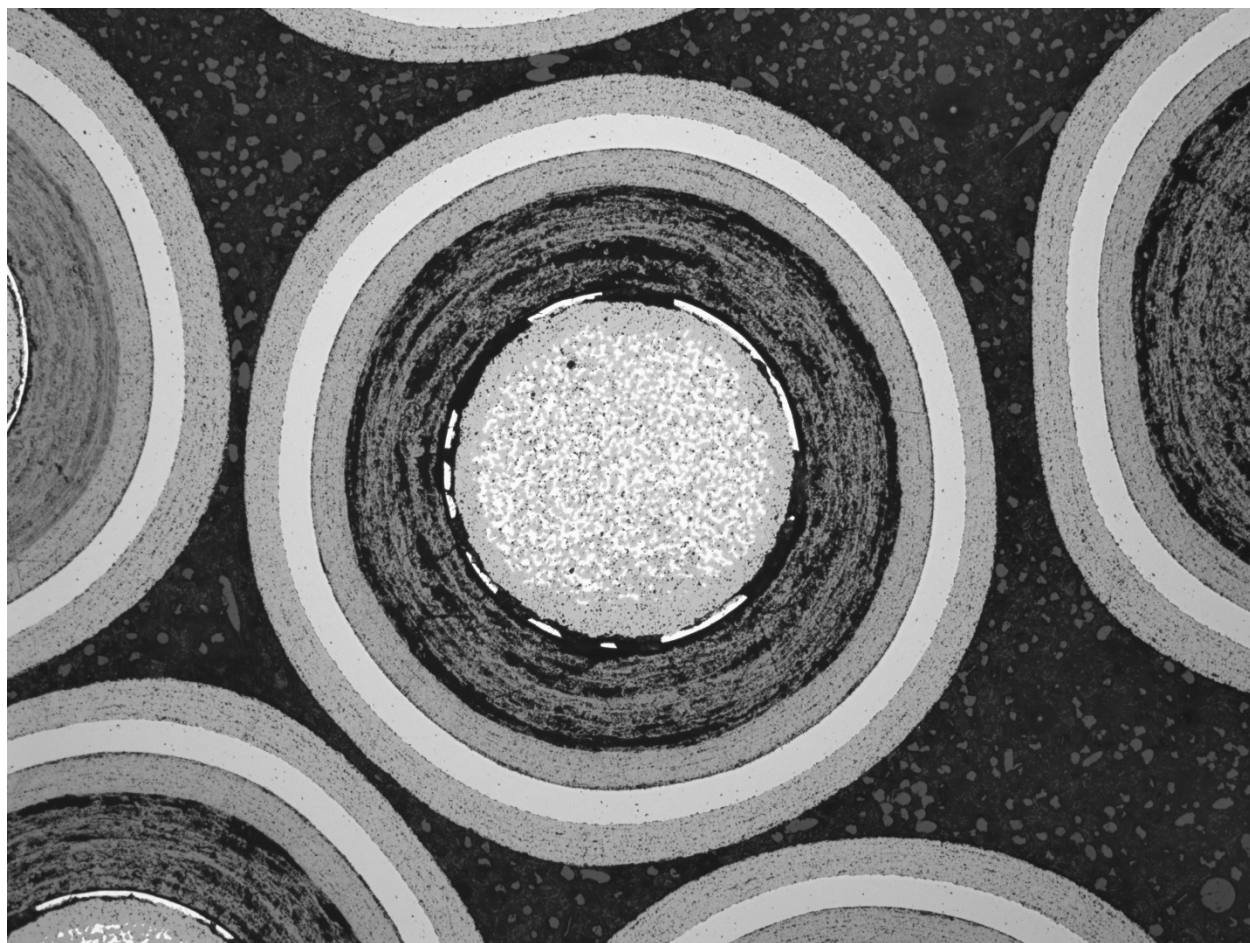
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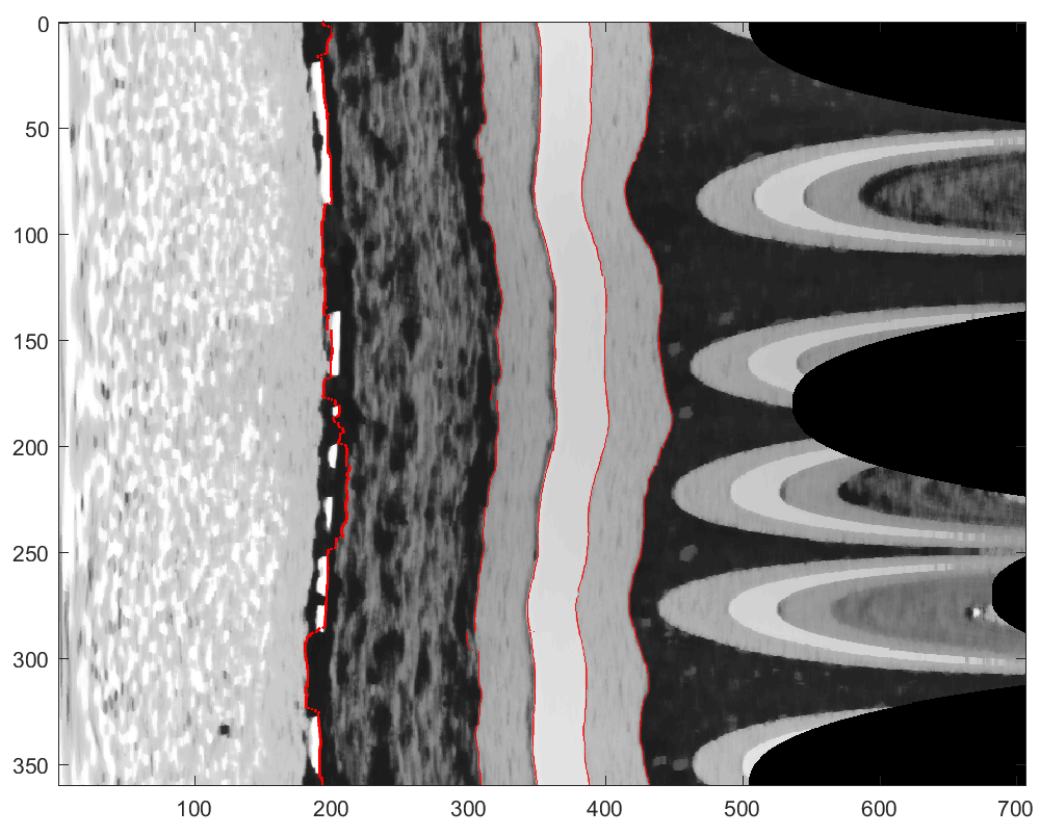
P16082301N153



**P16082301N153 unwrapped**

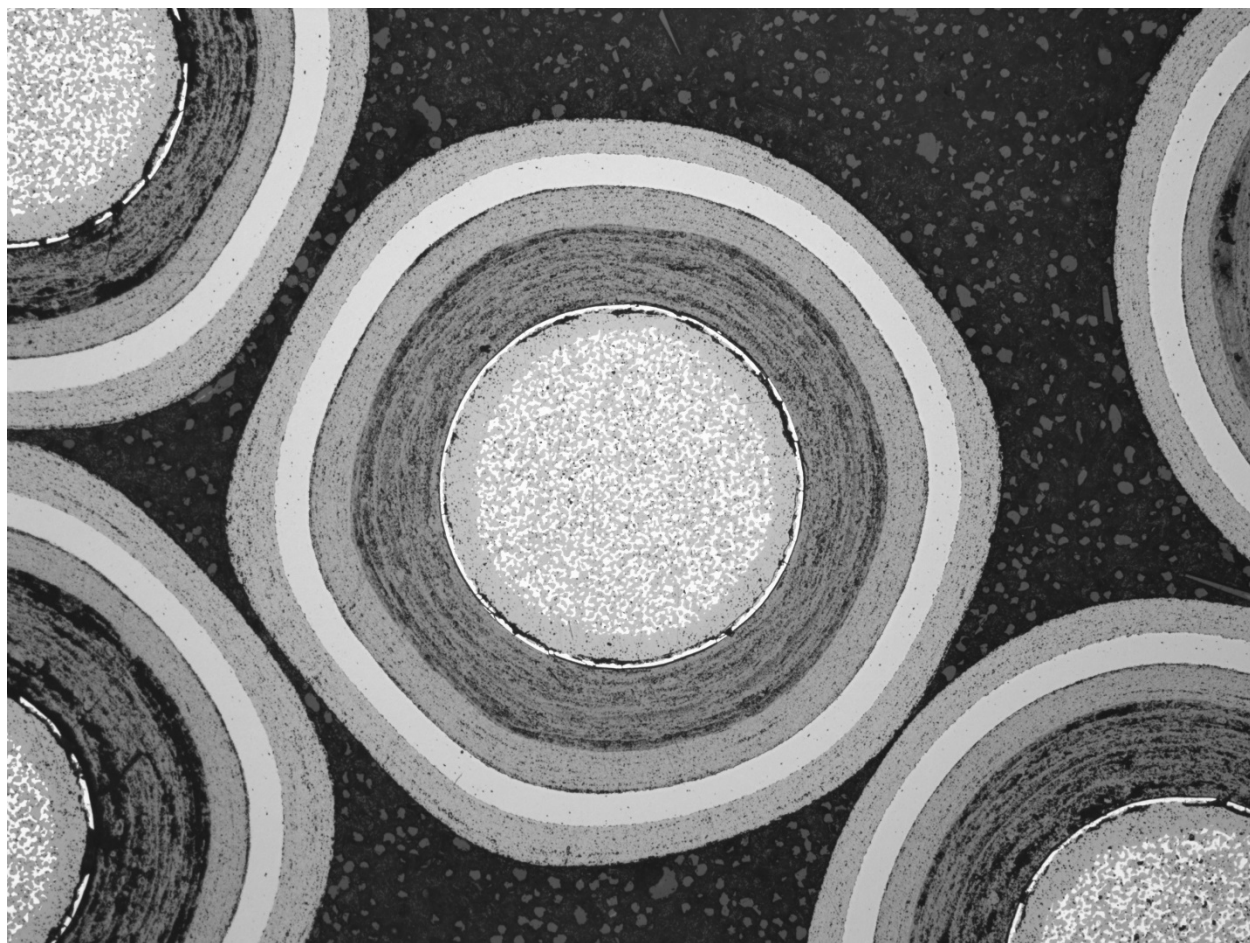


P16082301N154



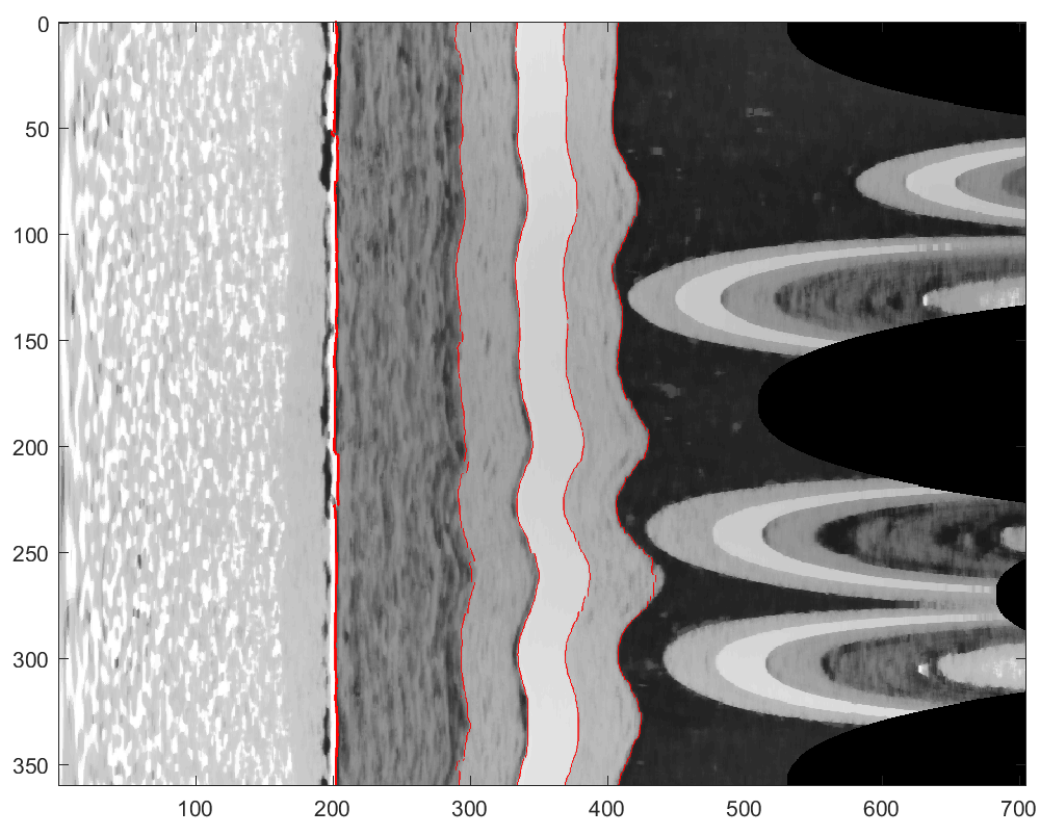
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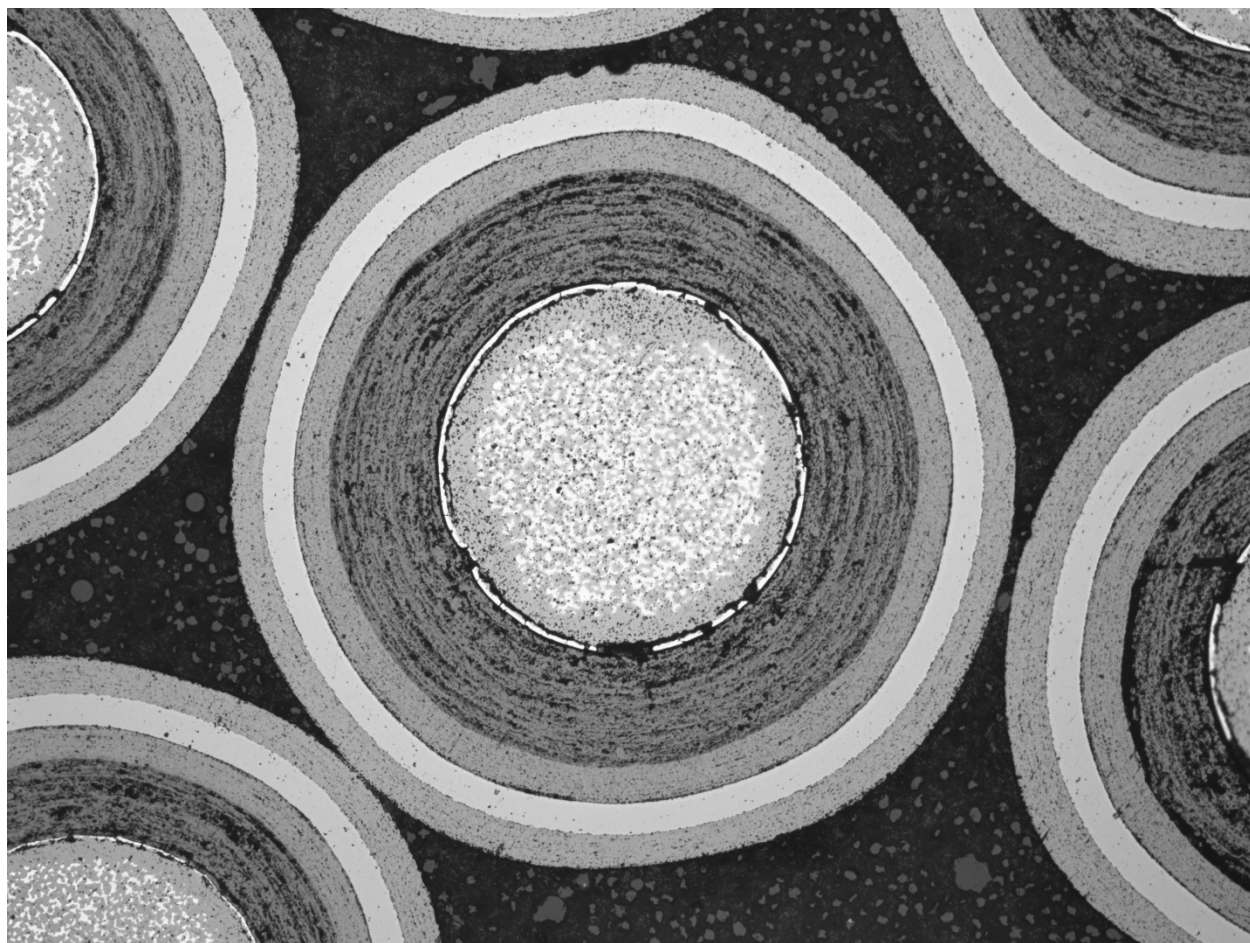


P16082301N155

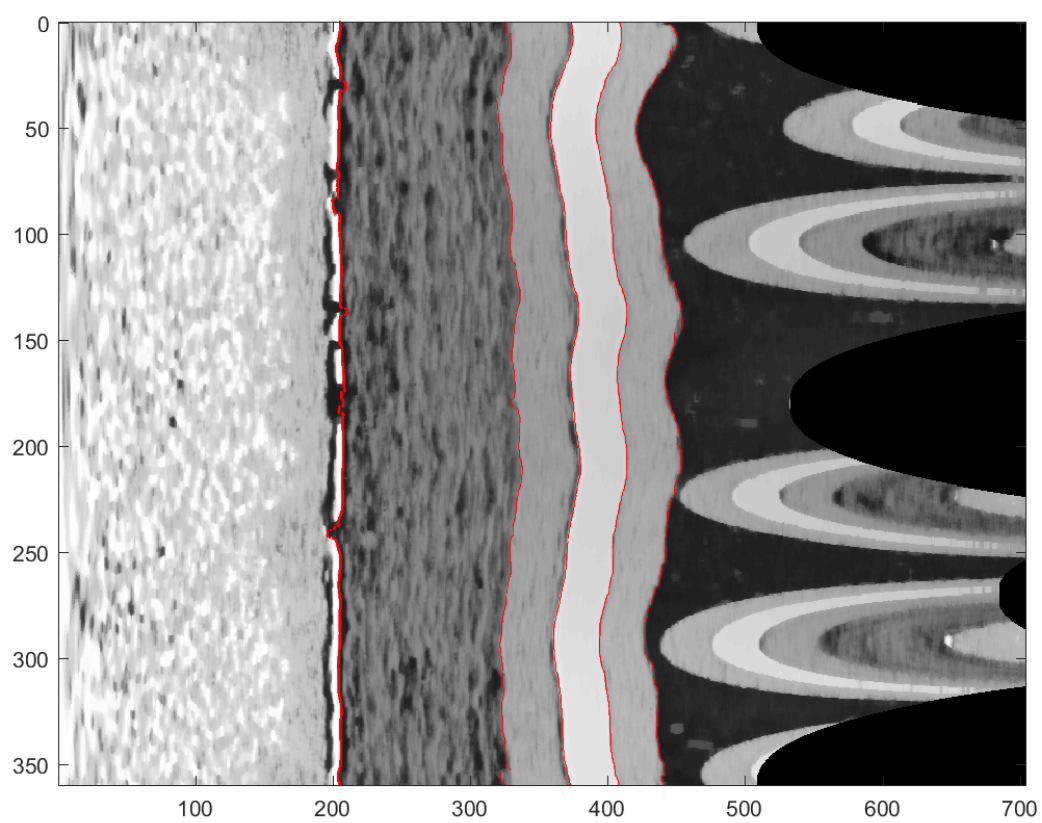




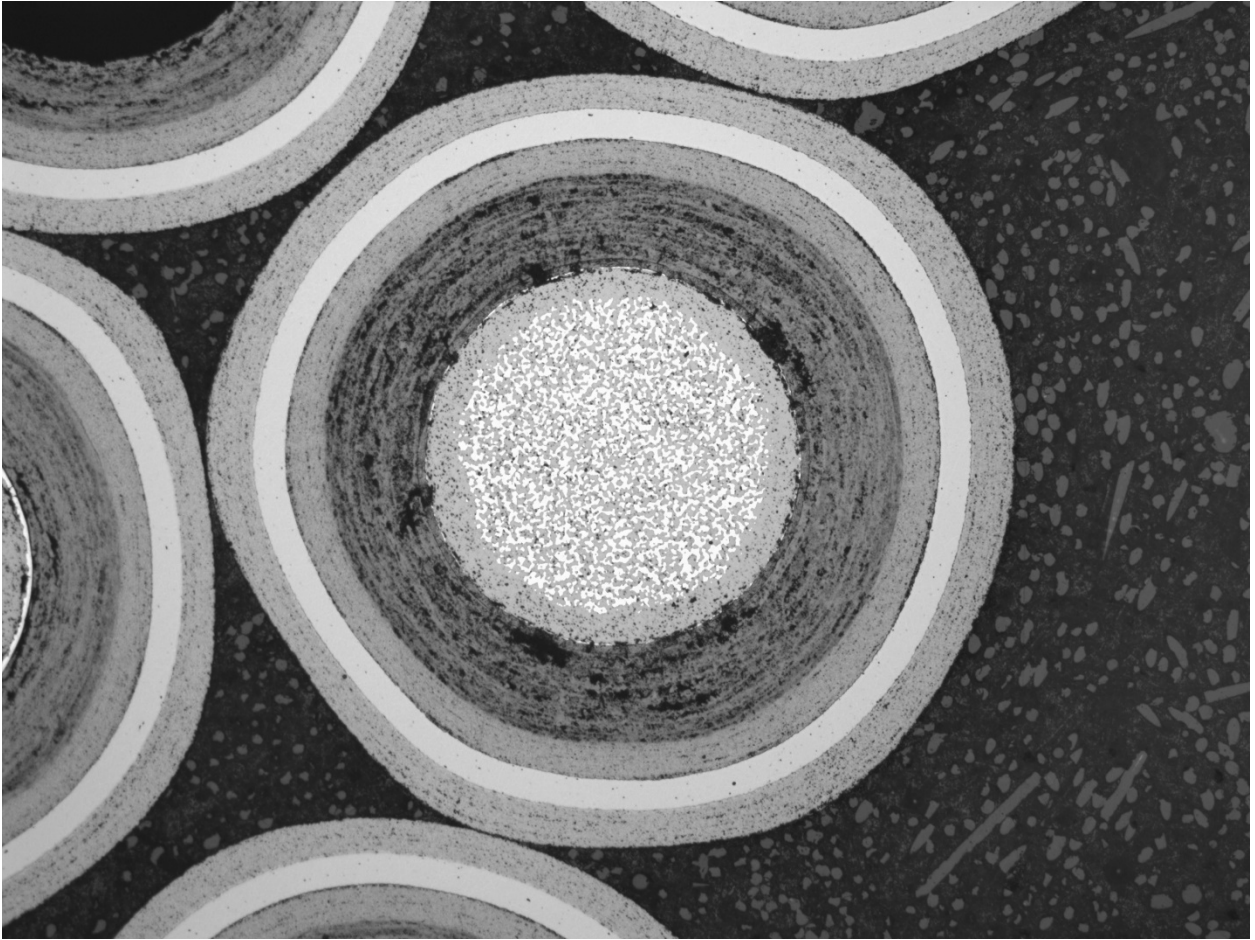
**P16082301N155 unwrapped**



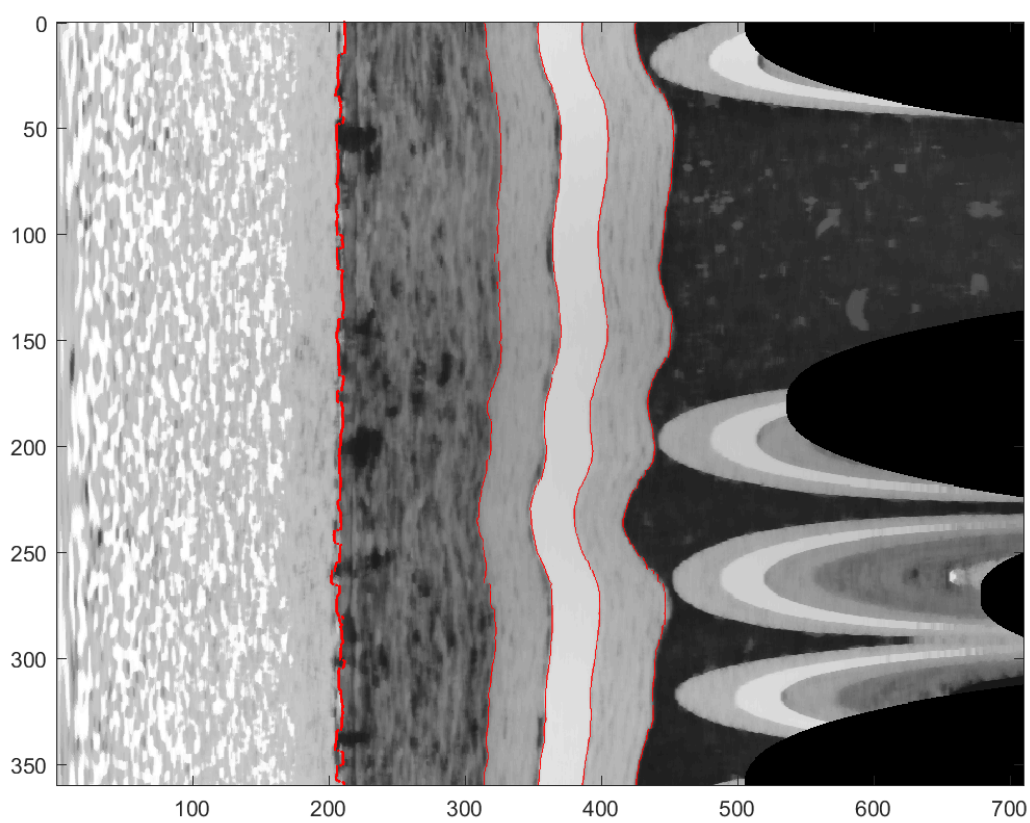
P16082301N156



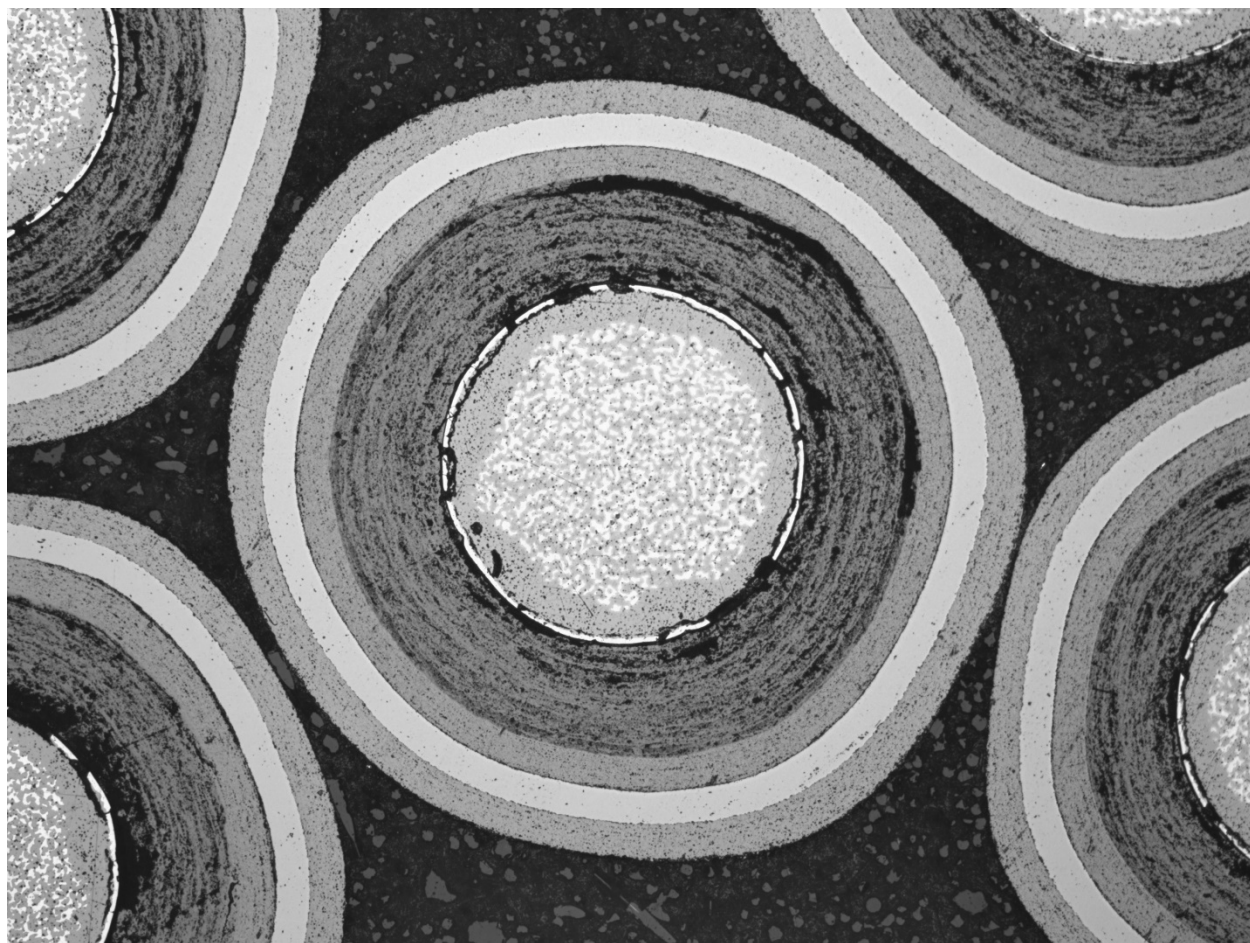
**P16082301N156 unwrapped**



P16082301N157

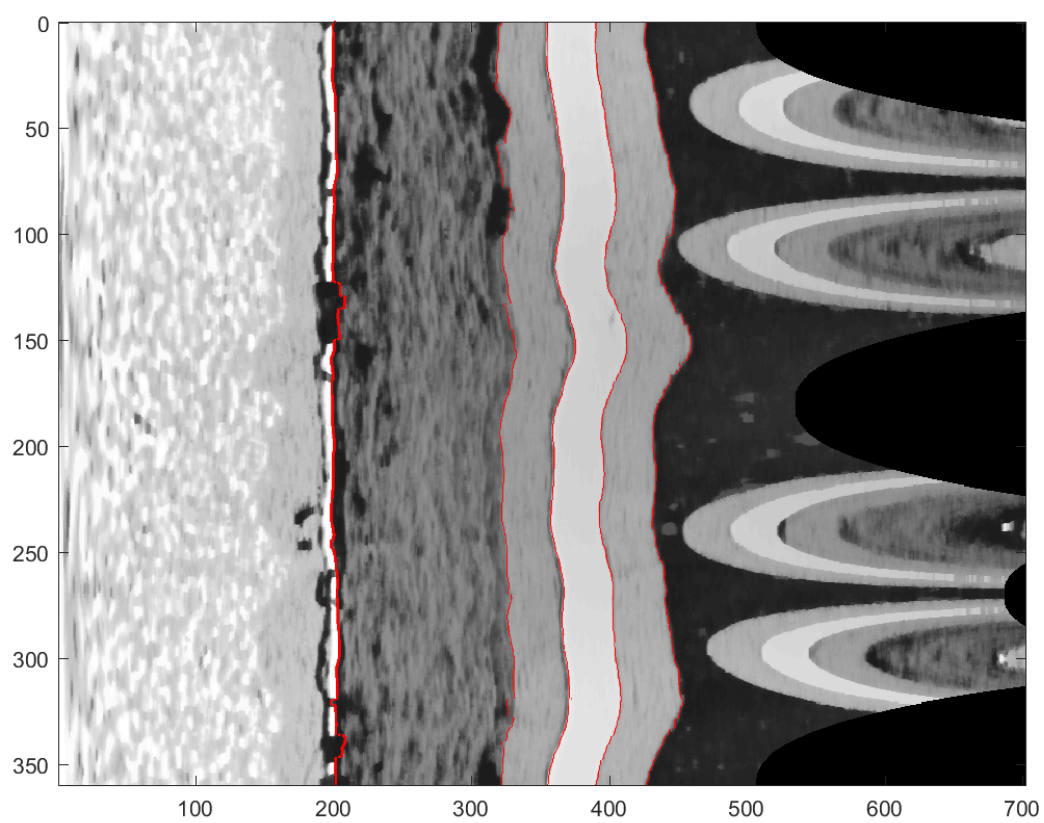


**P16082301N157 unwrapped**



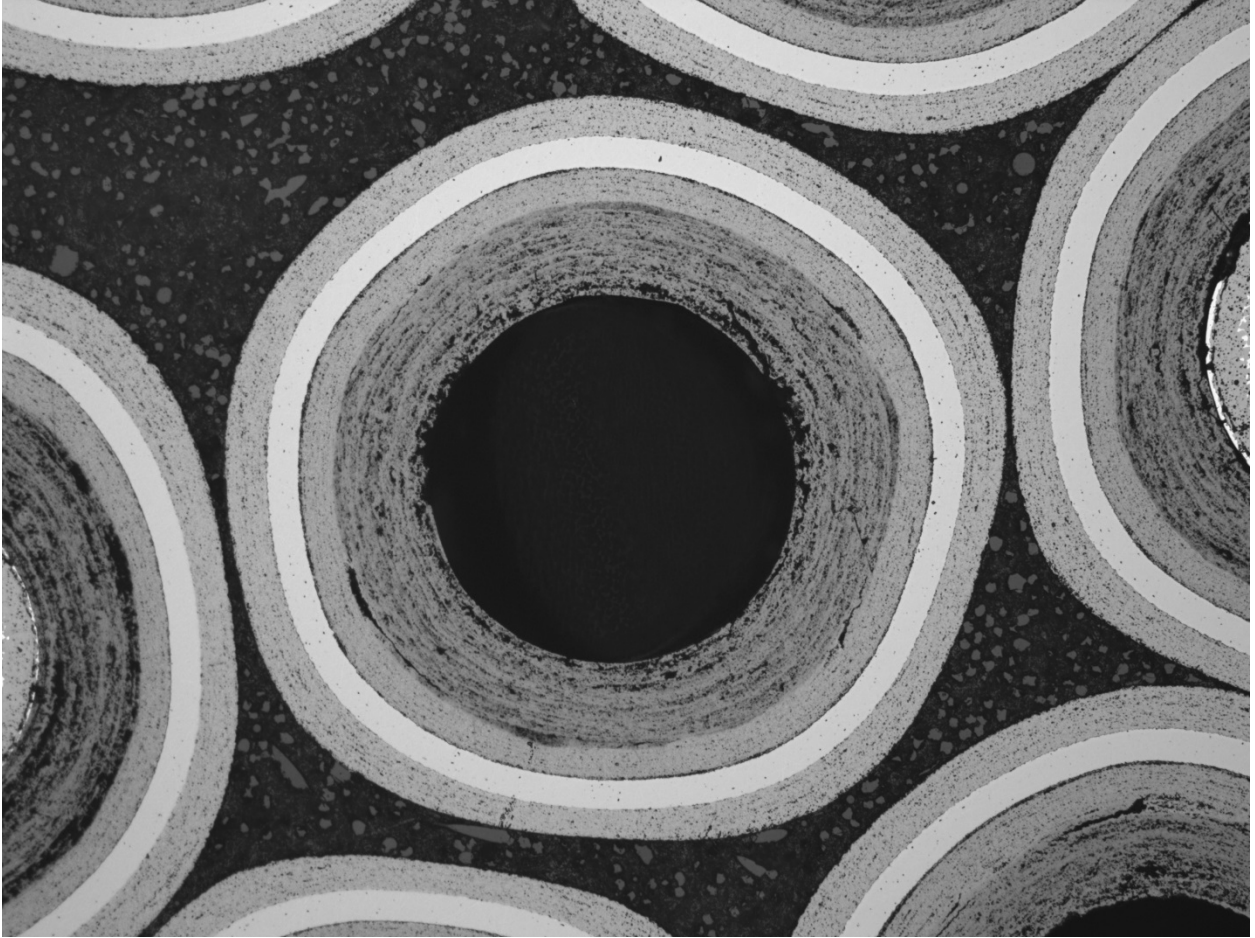
P16082301N158



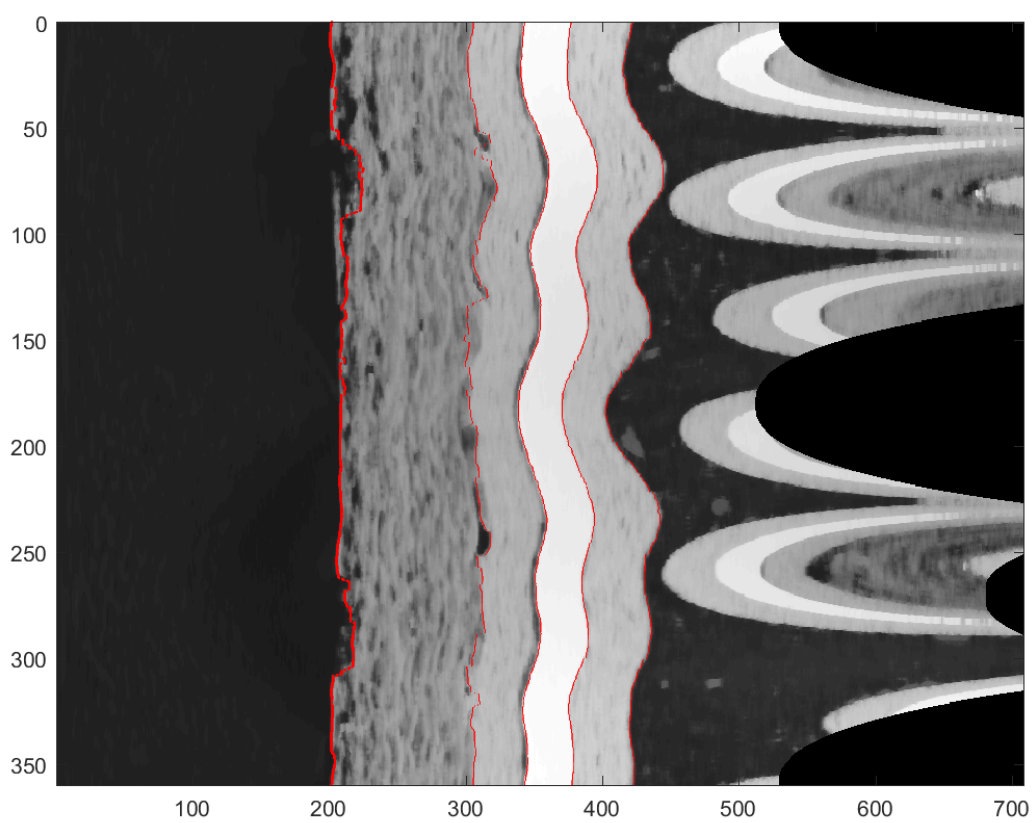


**P16082301N158 unwrapped**

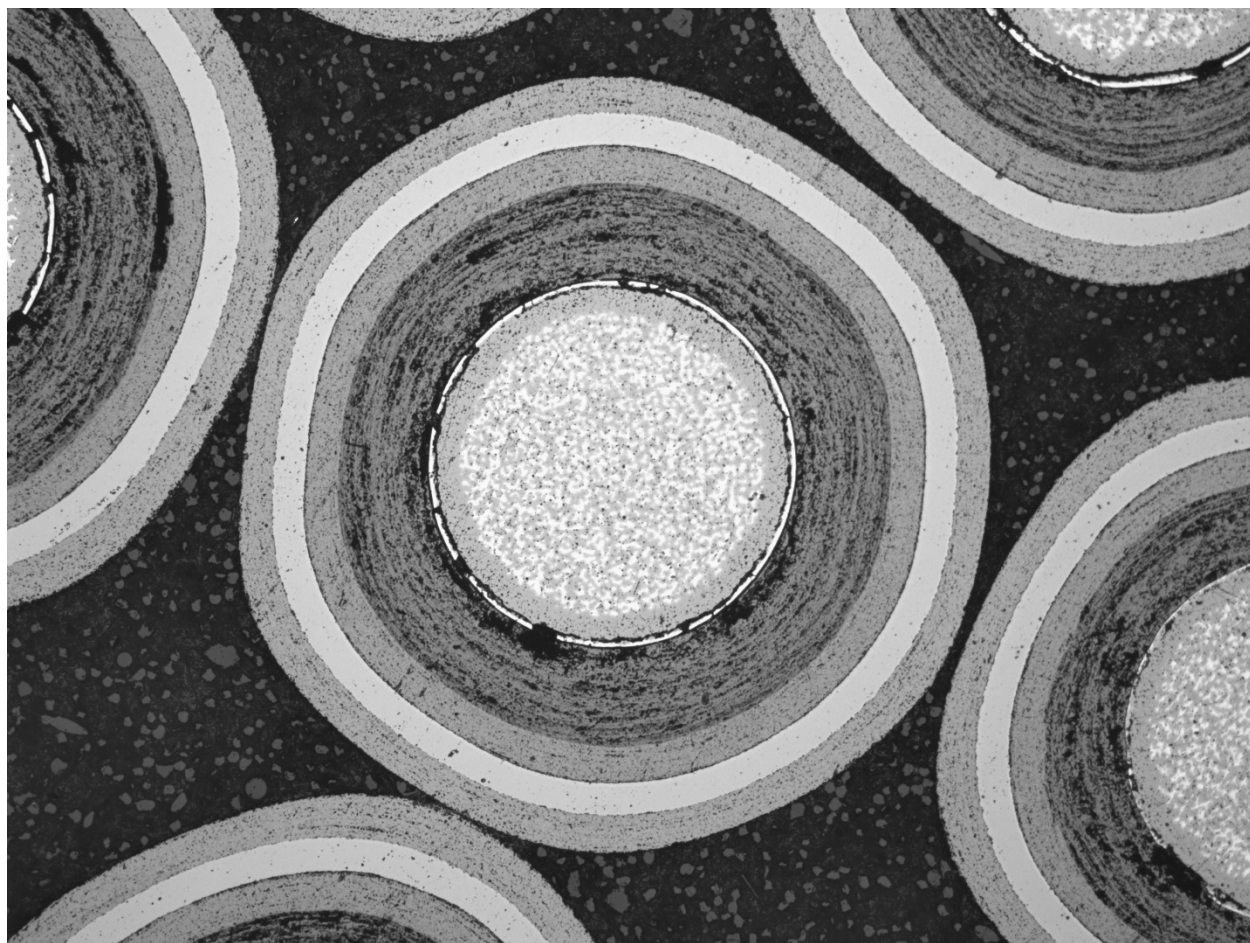




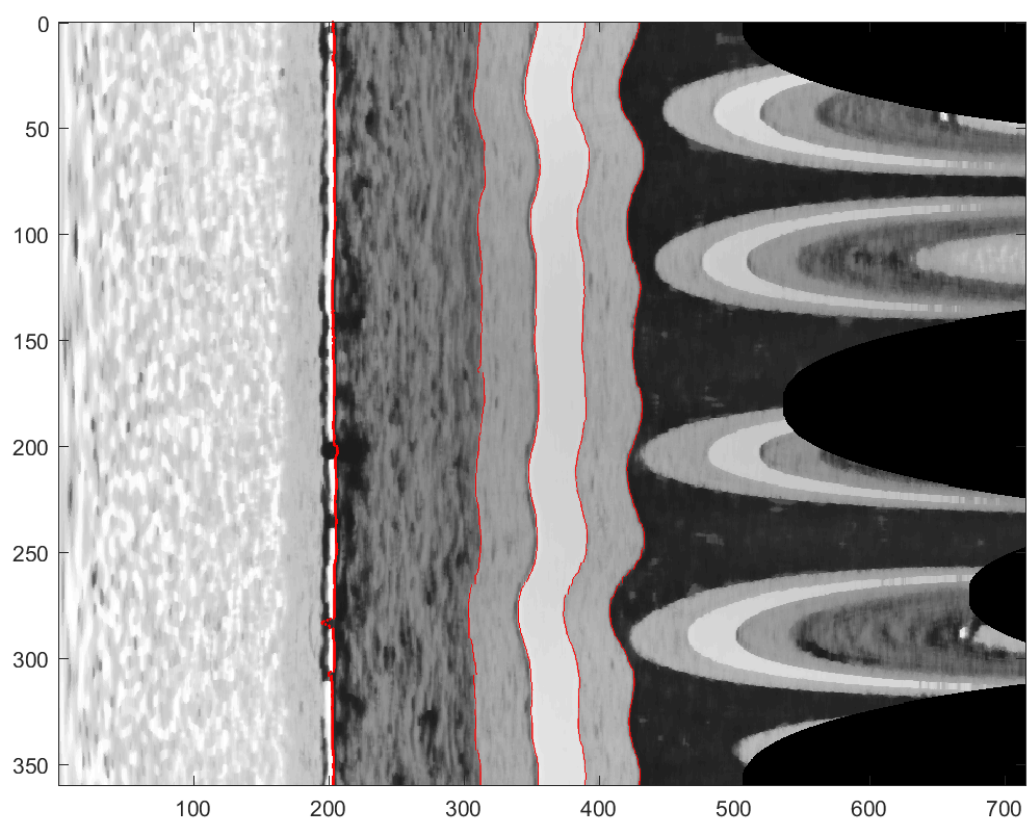
P16082301N160



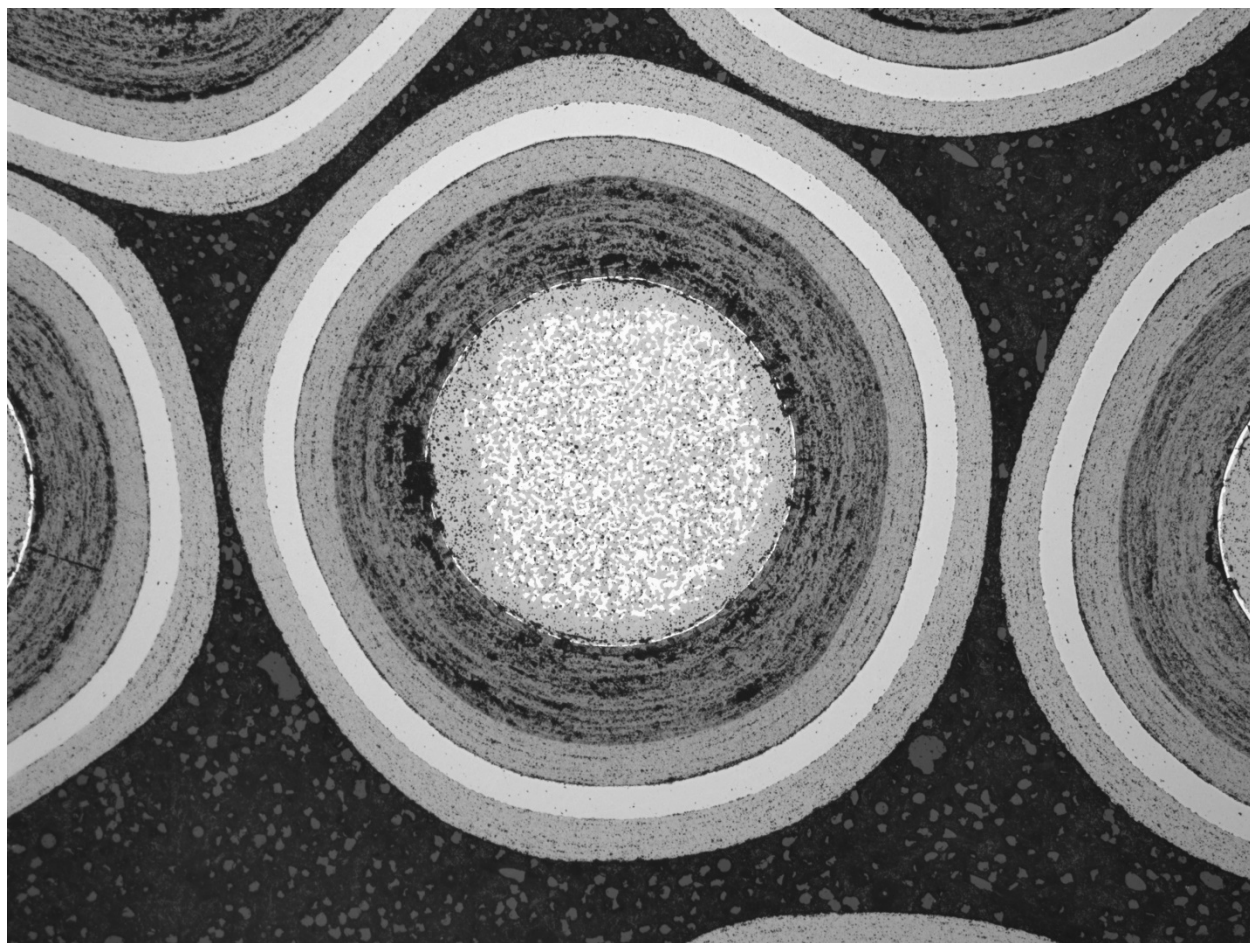
**P16082301N160 unwrapped**



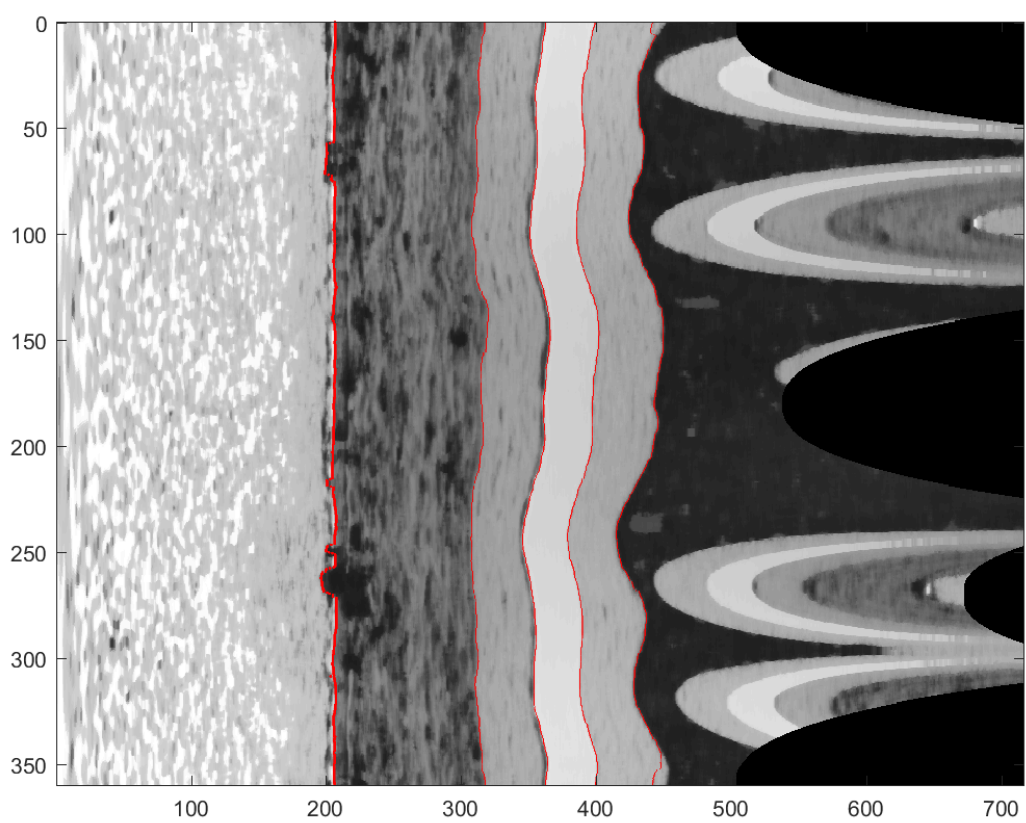
P16082301N161



**P16082301N161 unwrapped**

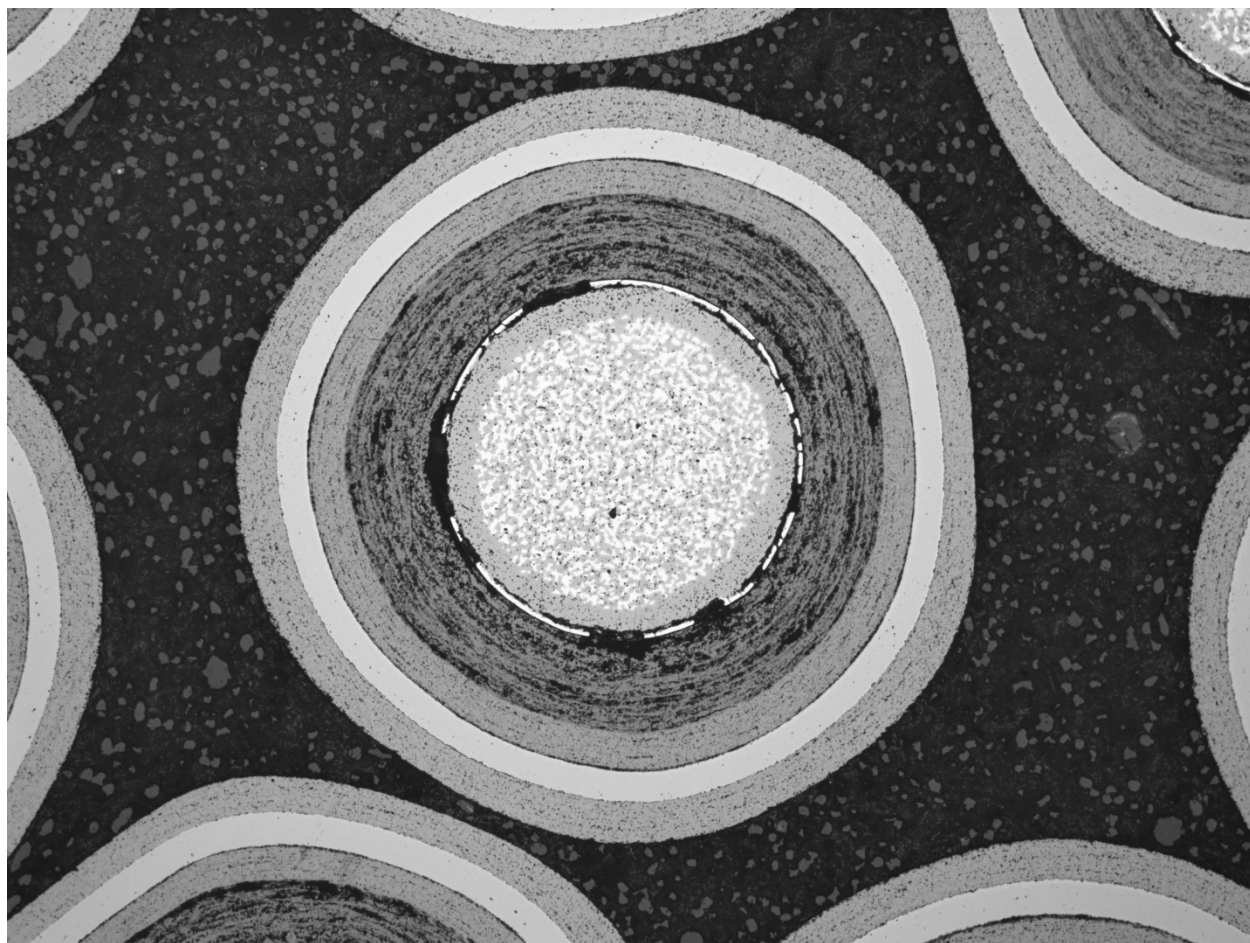


P16082301N163



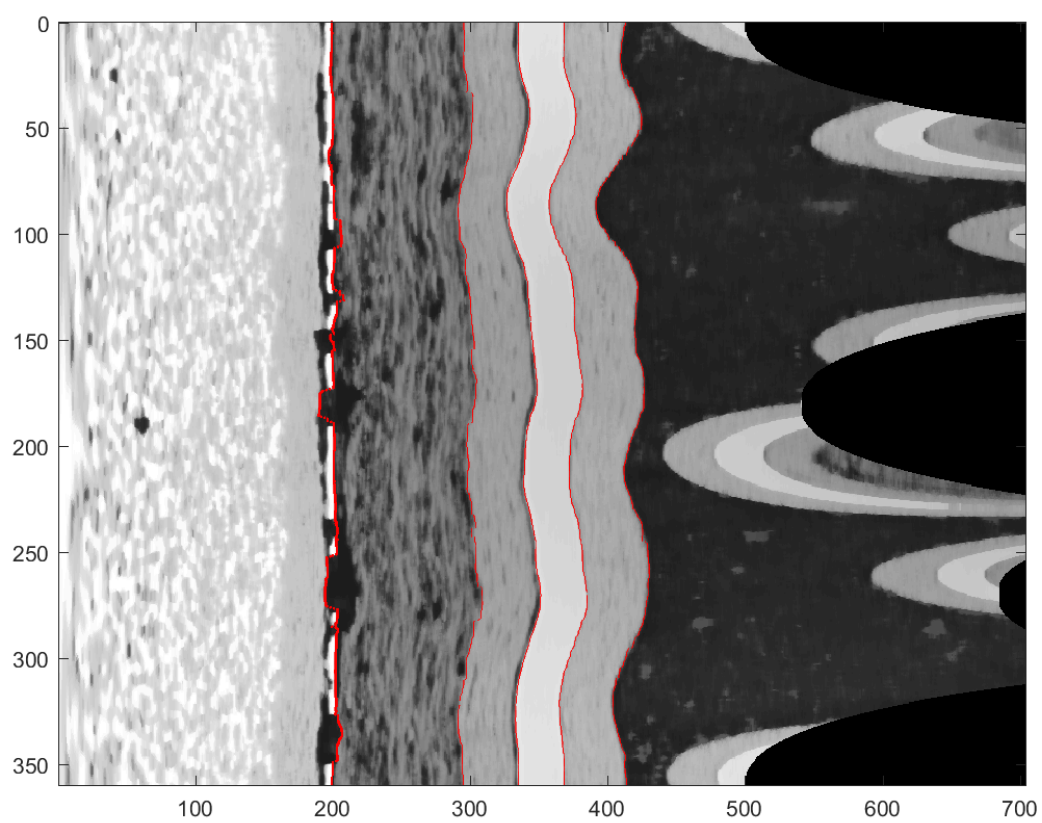
**P16082301N163 unwrapped**



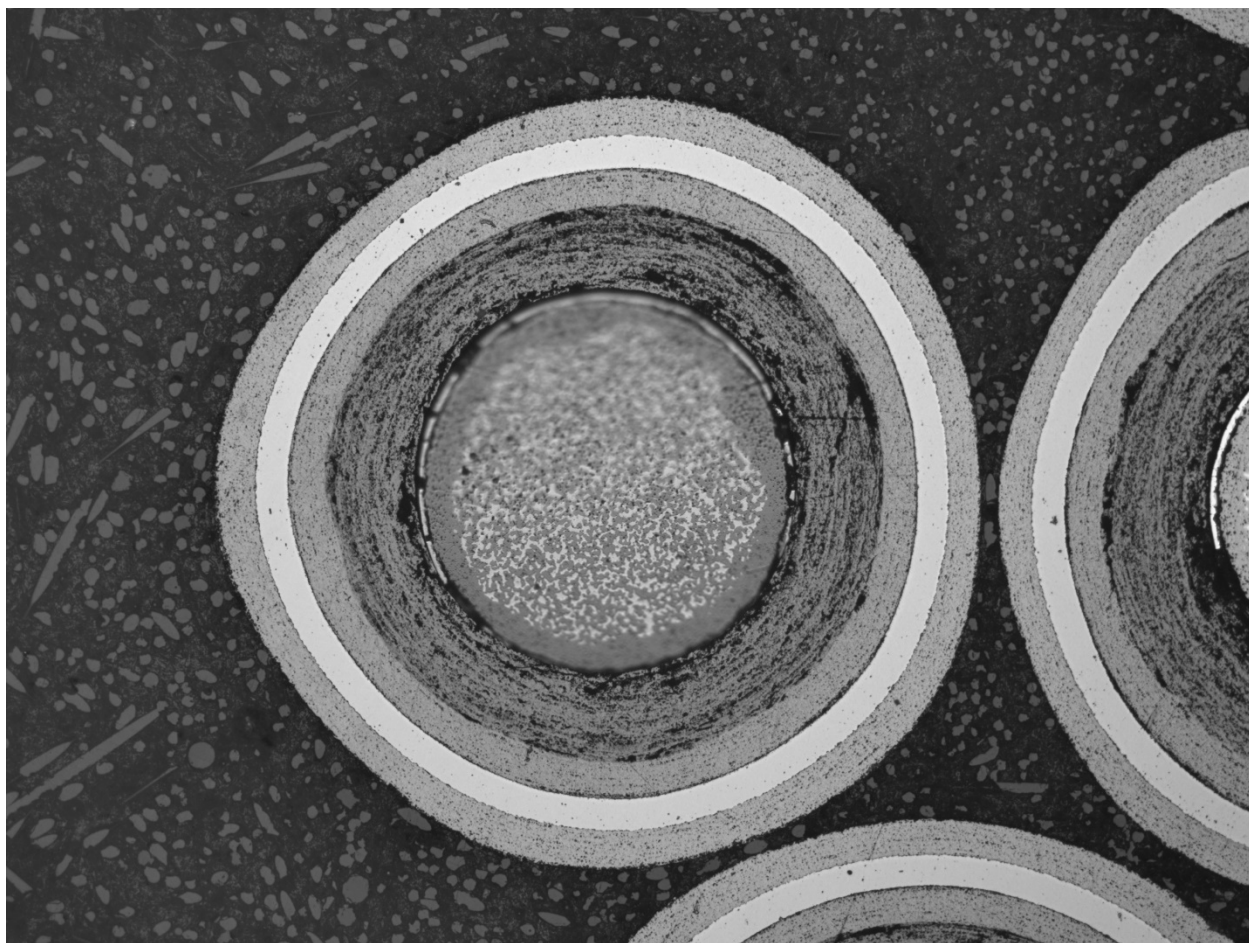


P16082301N164

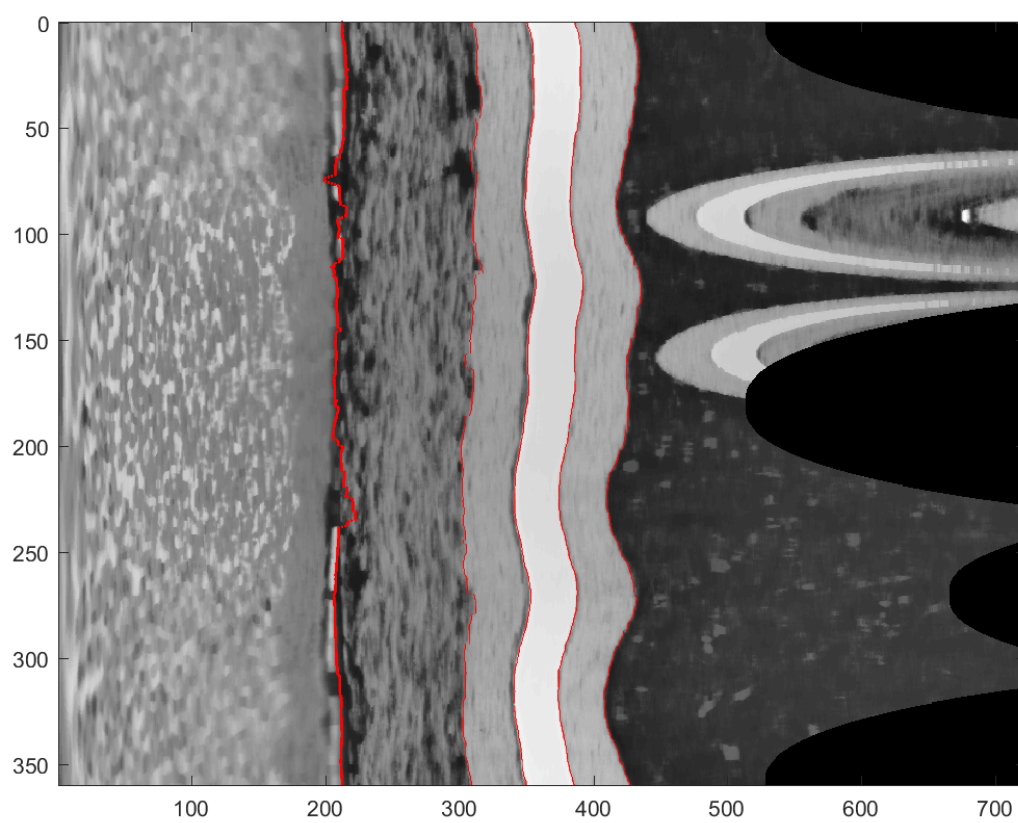




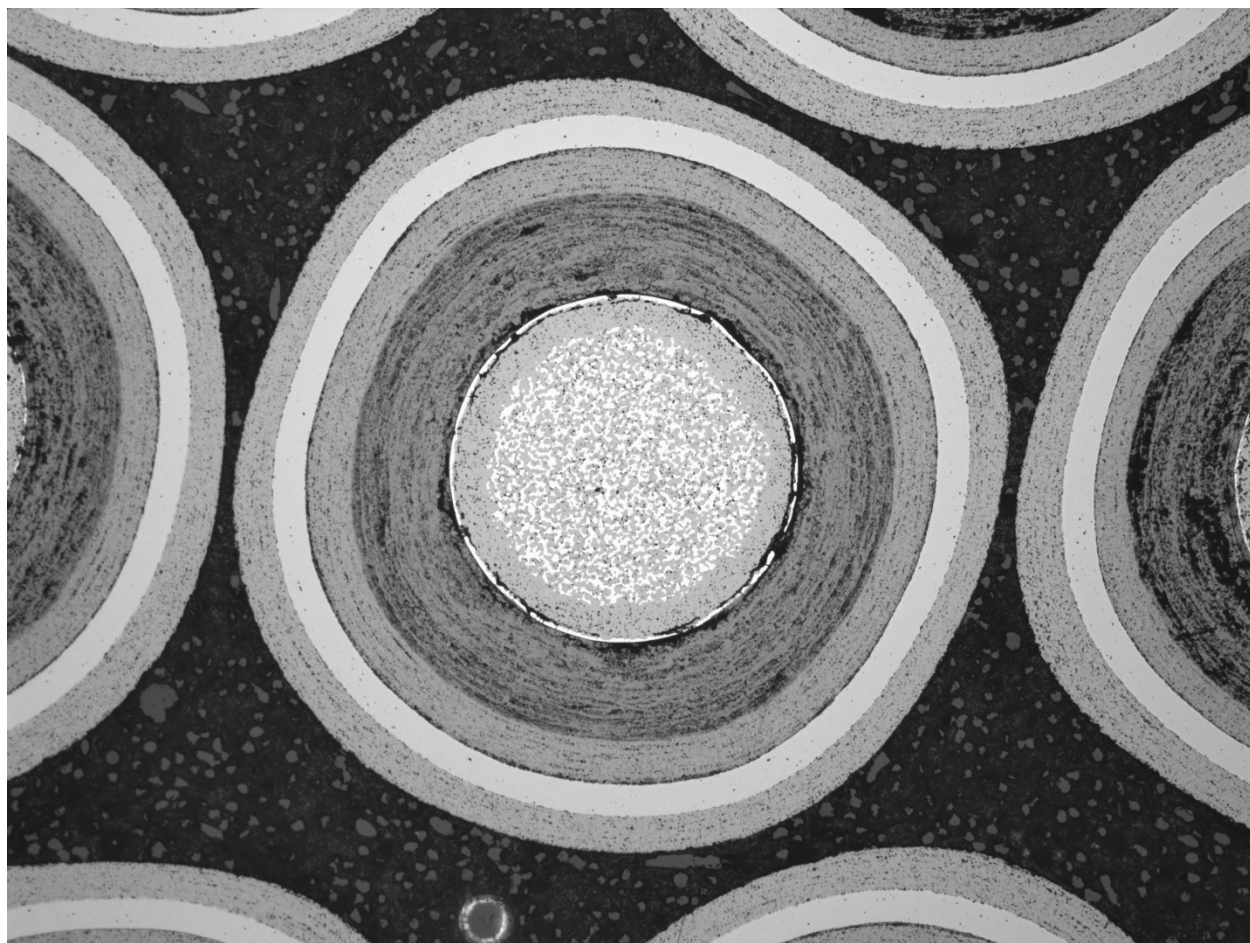
**P16082301N164 unwrapped**



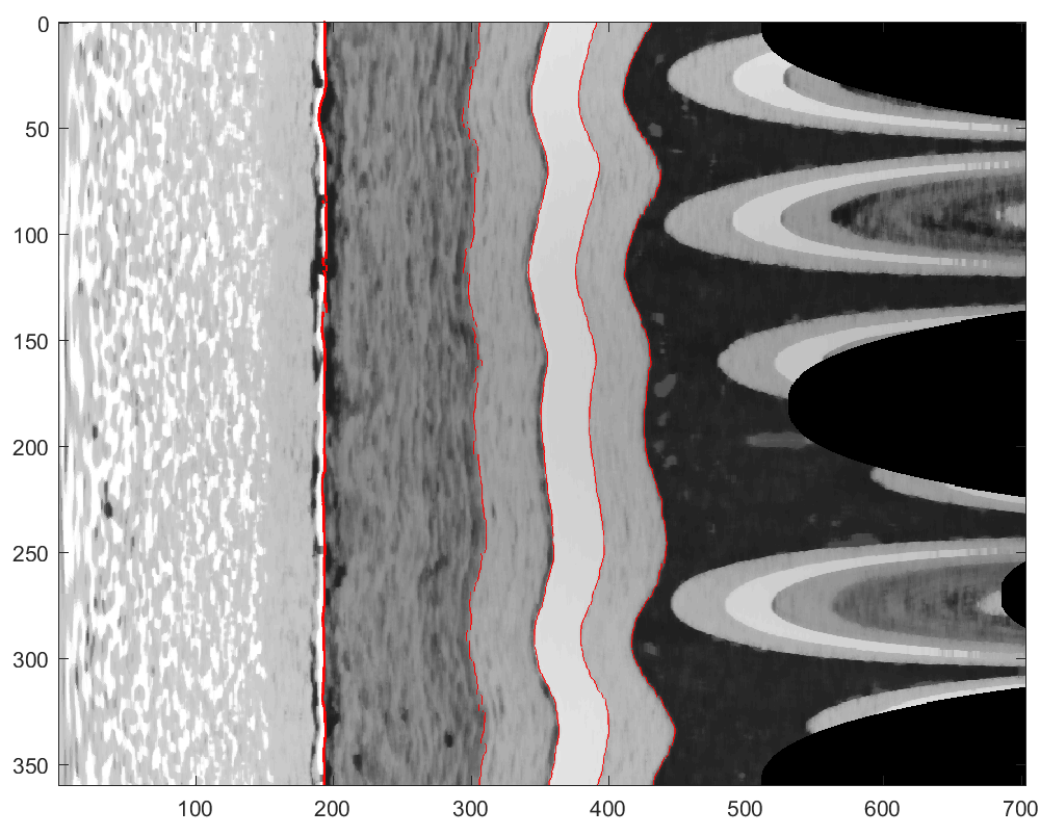
P16082301N165



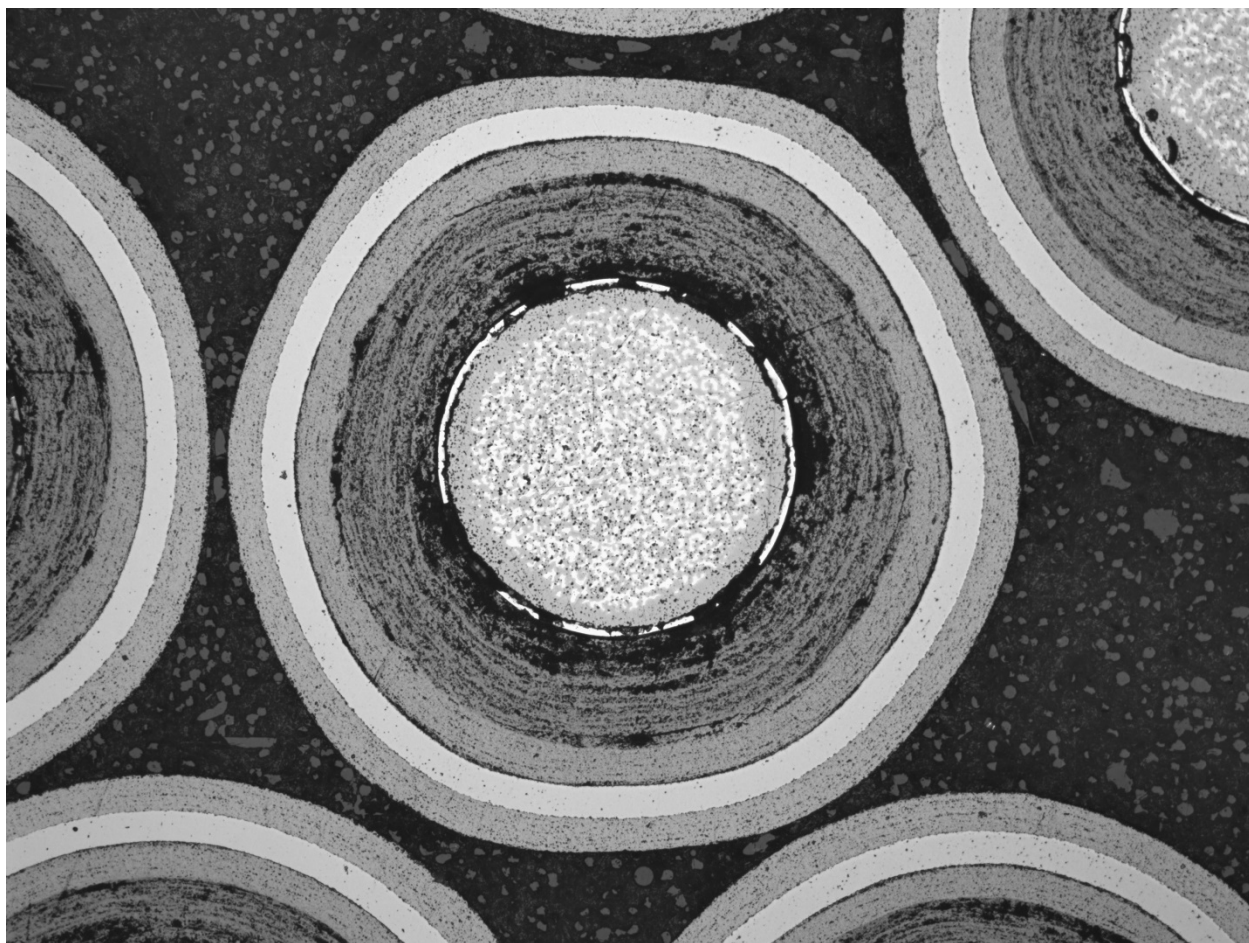
**P16082301N165 unwrapped**



P16082301N168

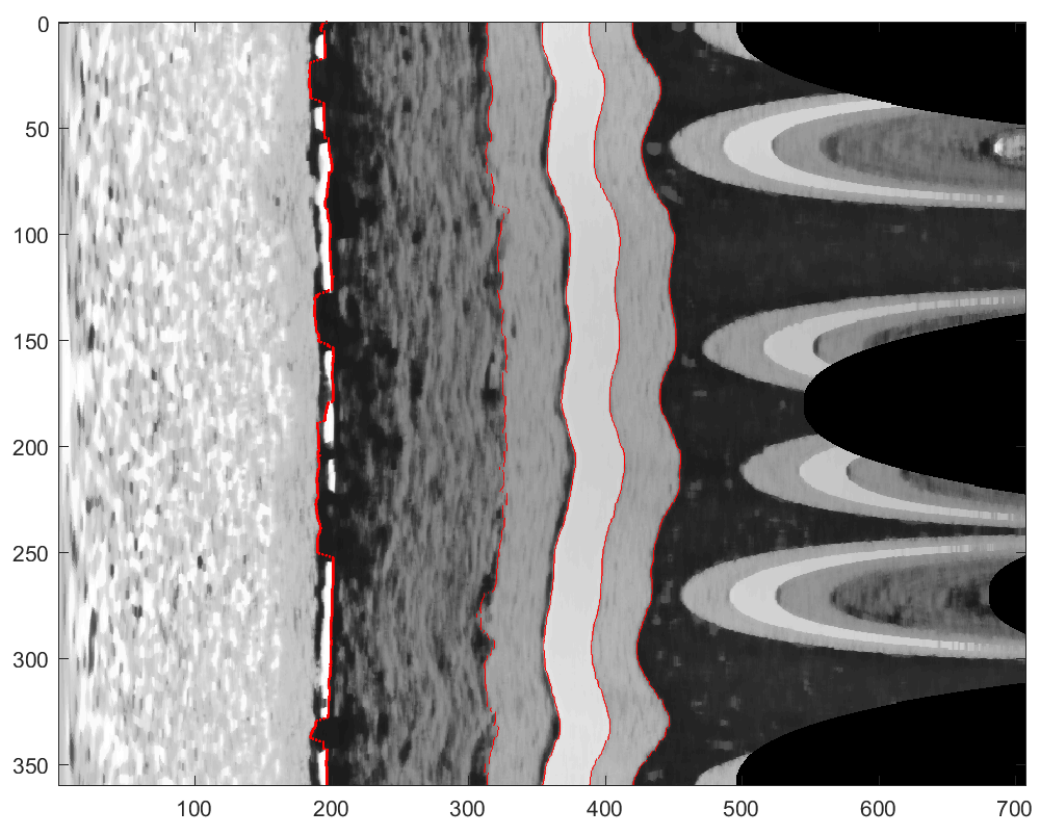


**P16082301N168 unwrapped**



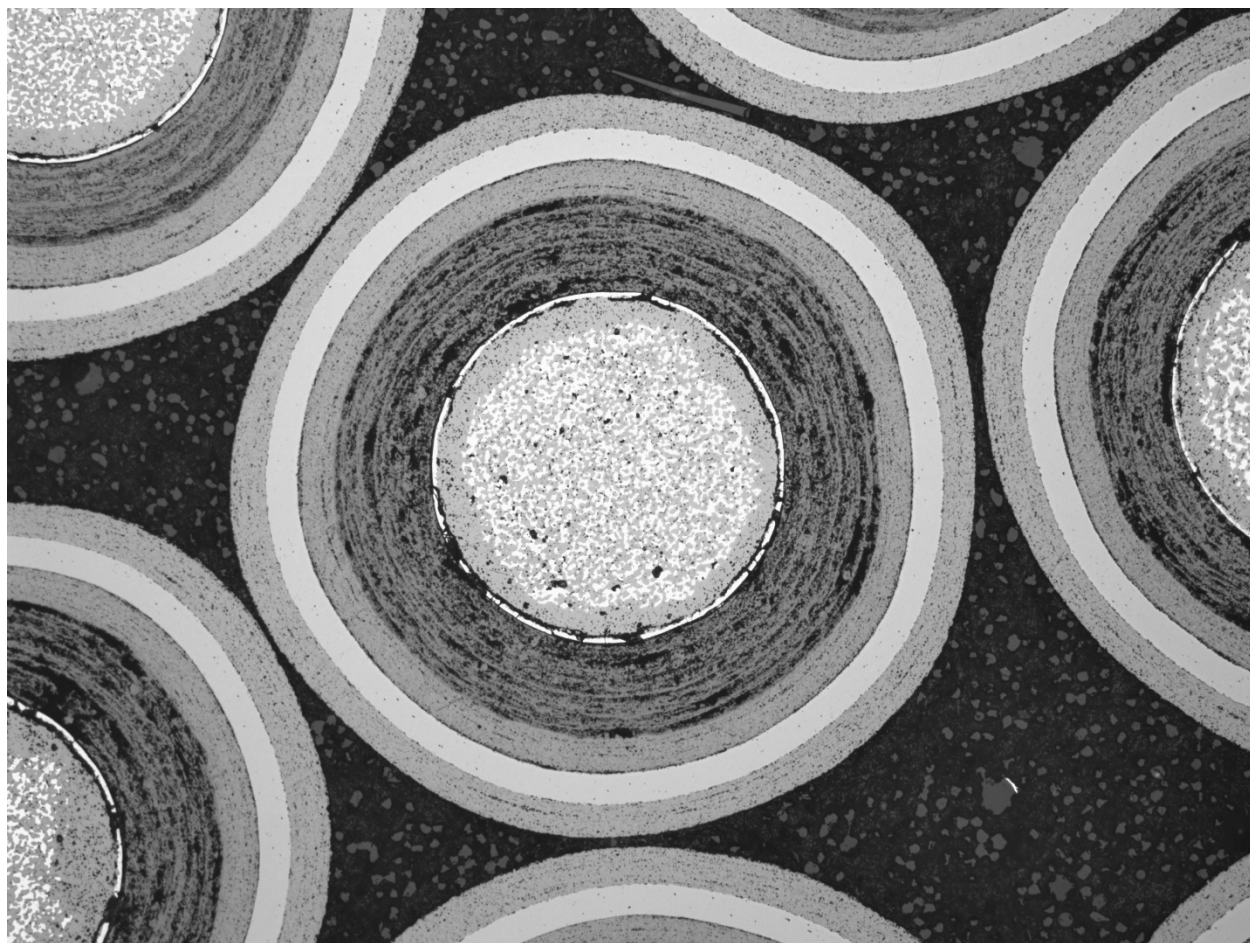
P16082301N169



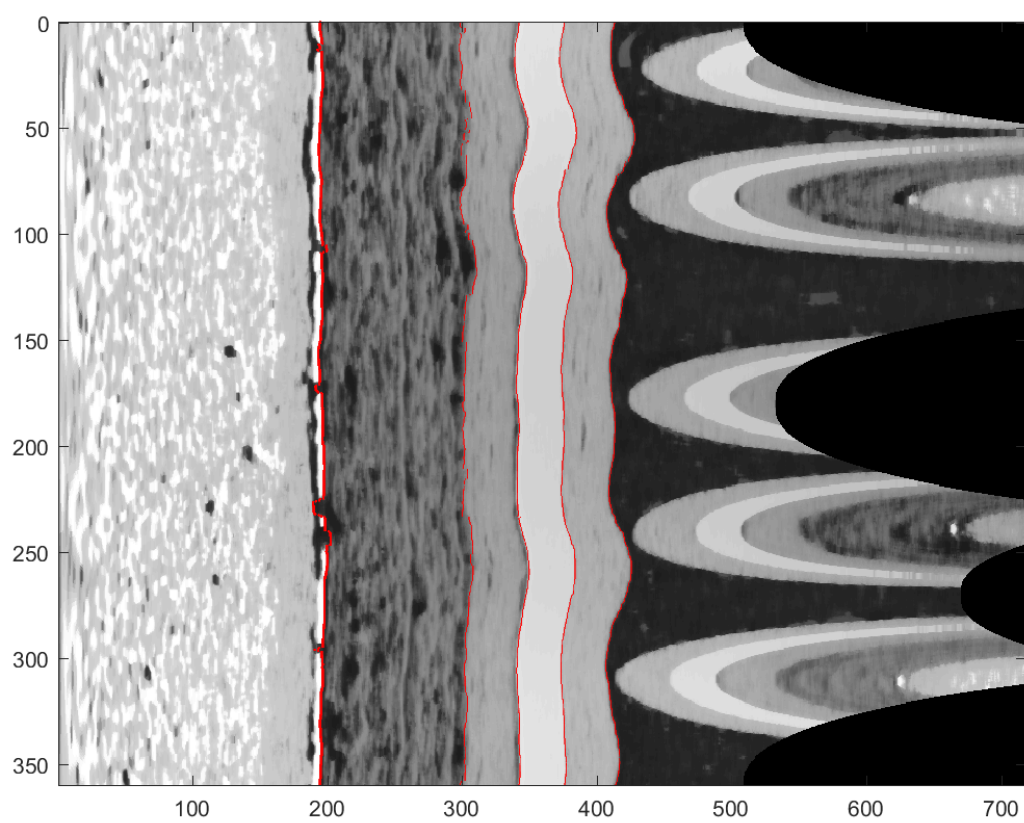


**P16082301N169 unwrapped**

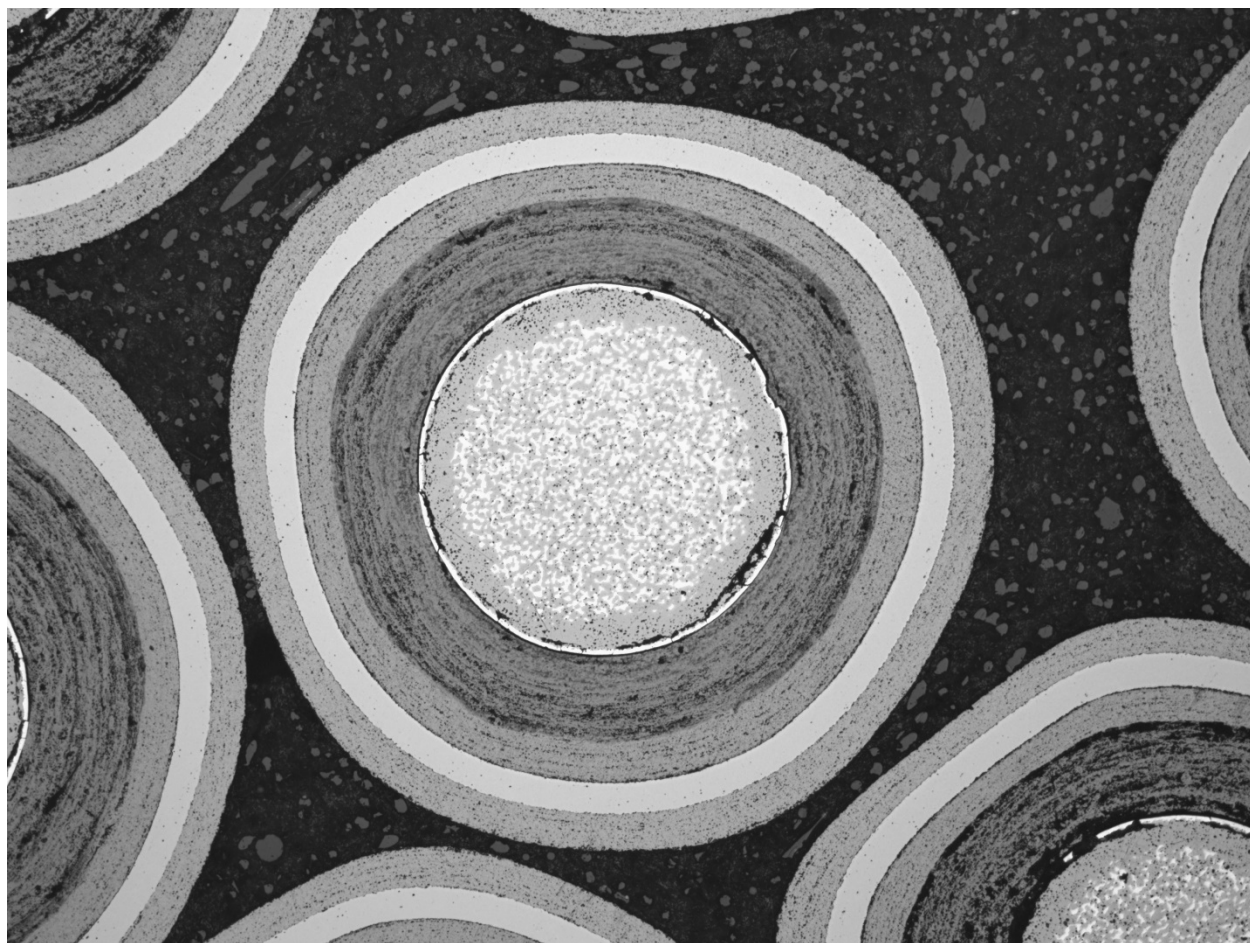




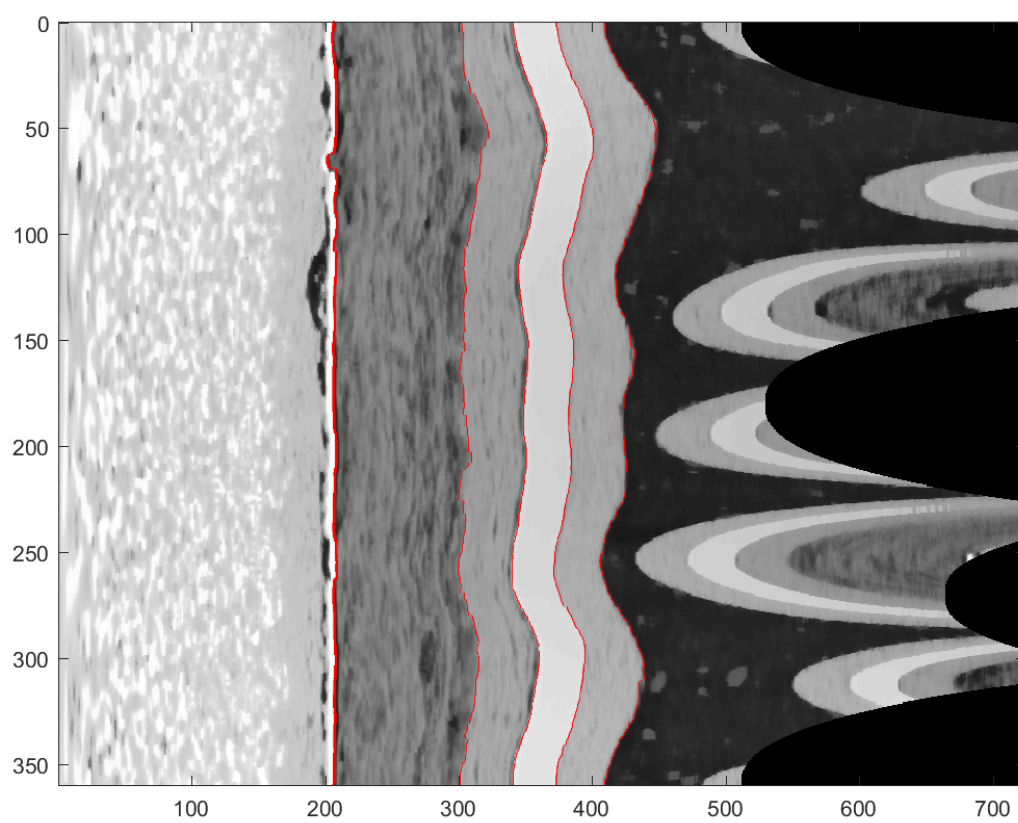
P16082301N170



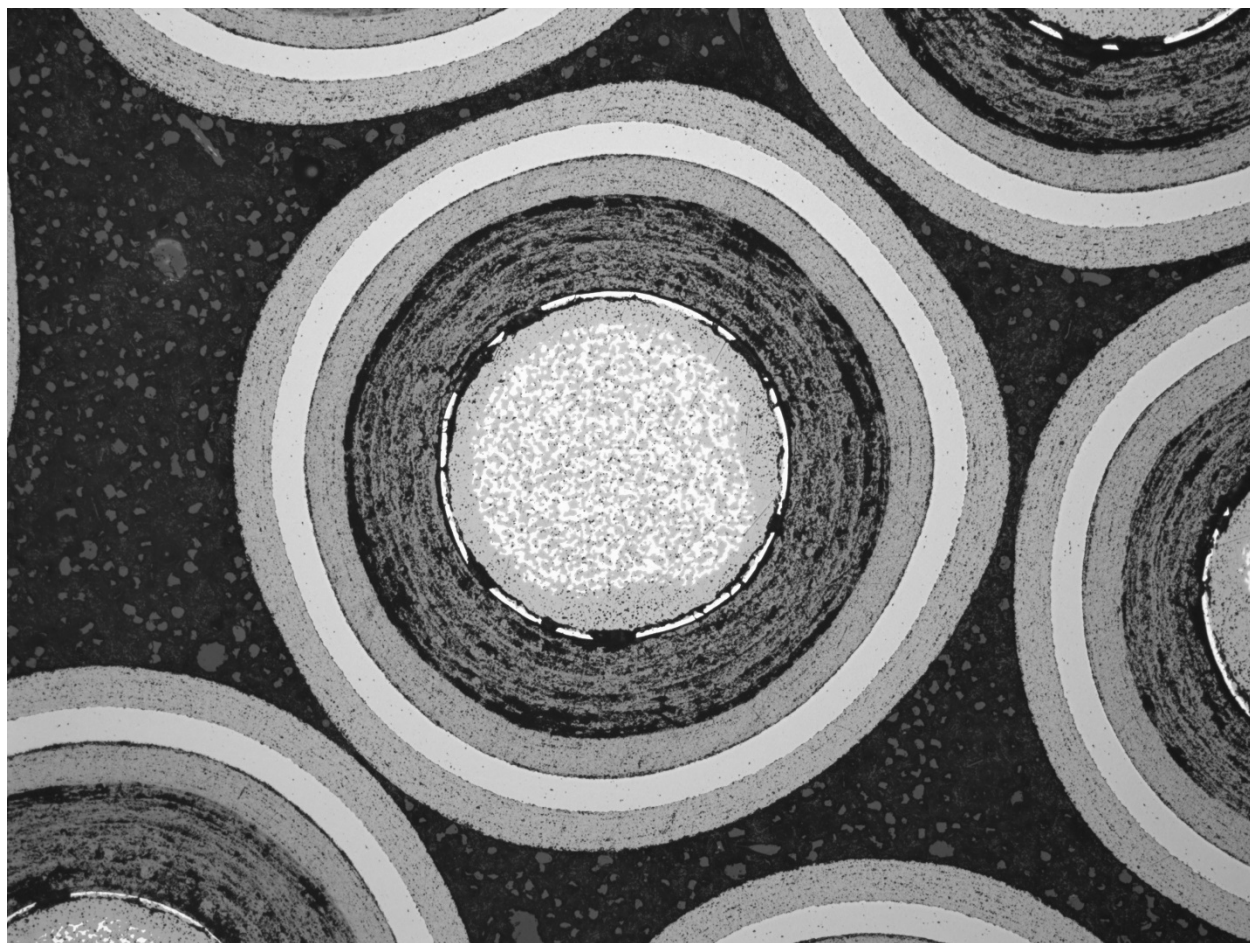
**P16082301N170 unwrapped**



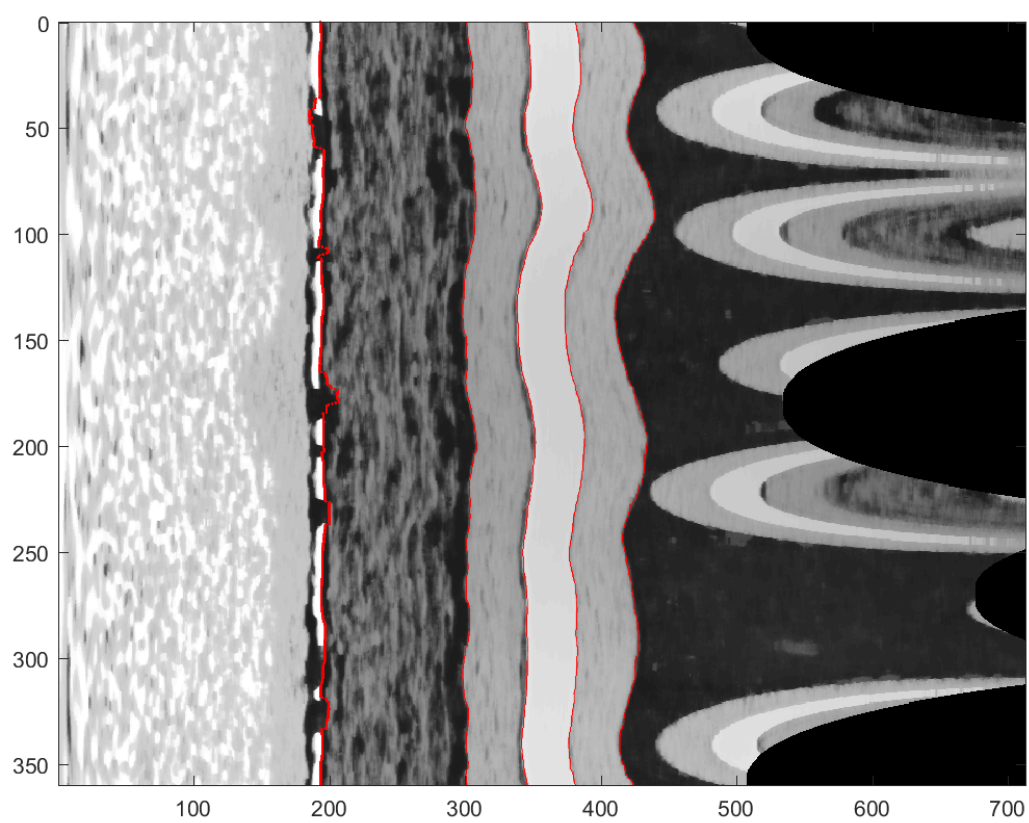
P16082301N171



**P16082301N171 unwrapped**

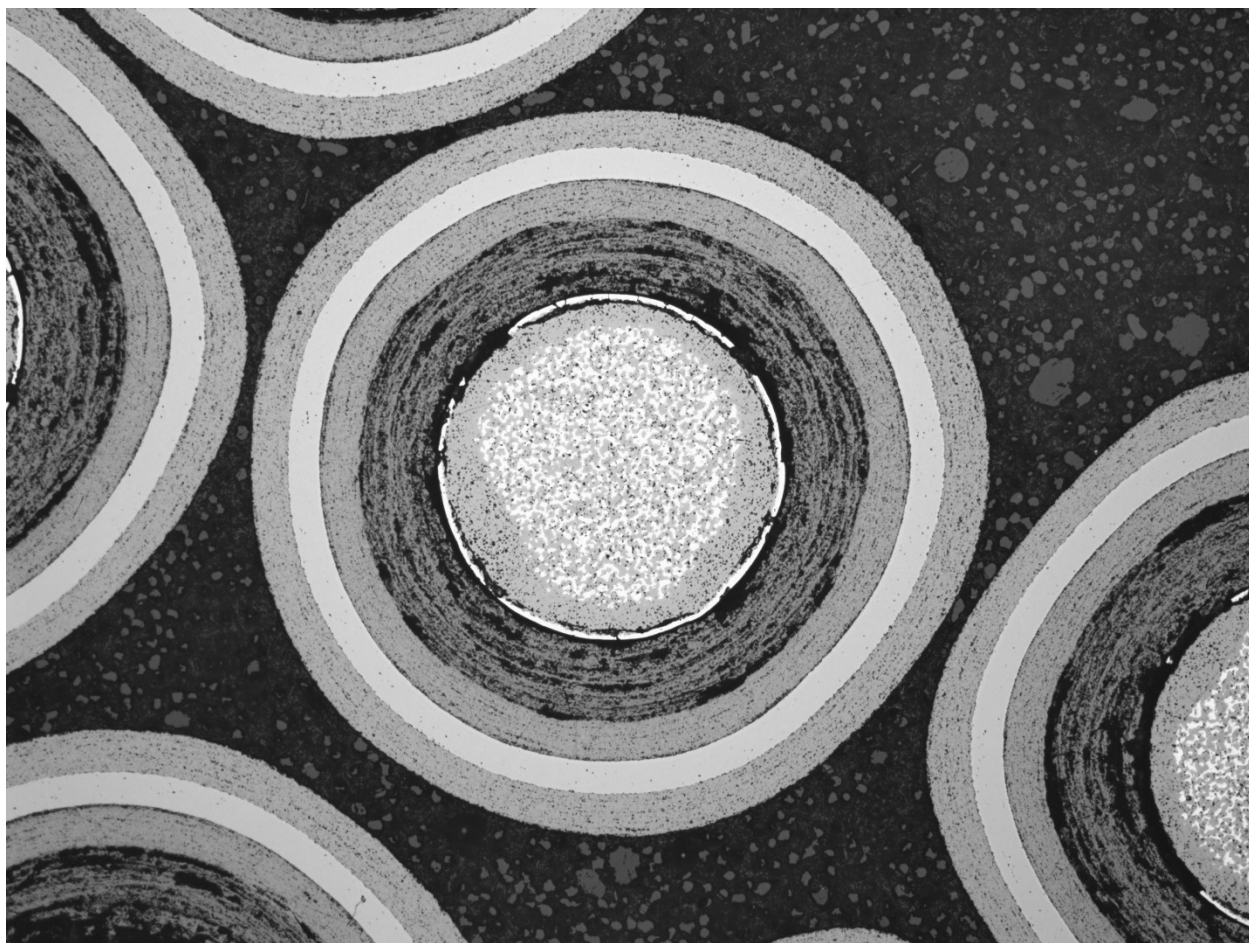


P16082301N172



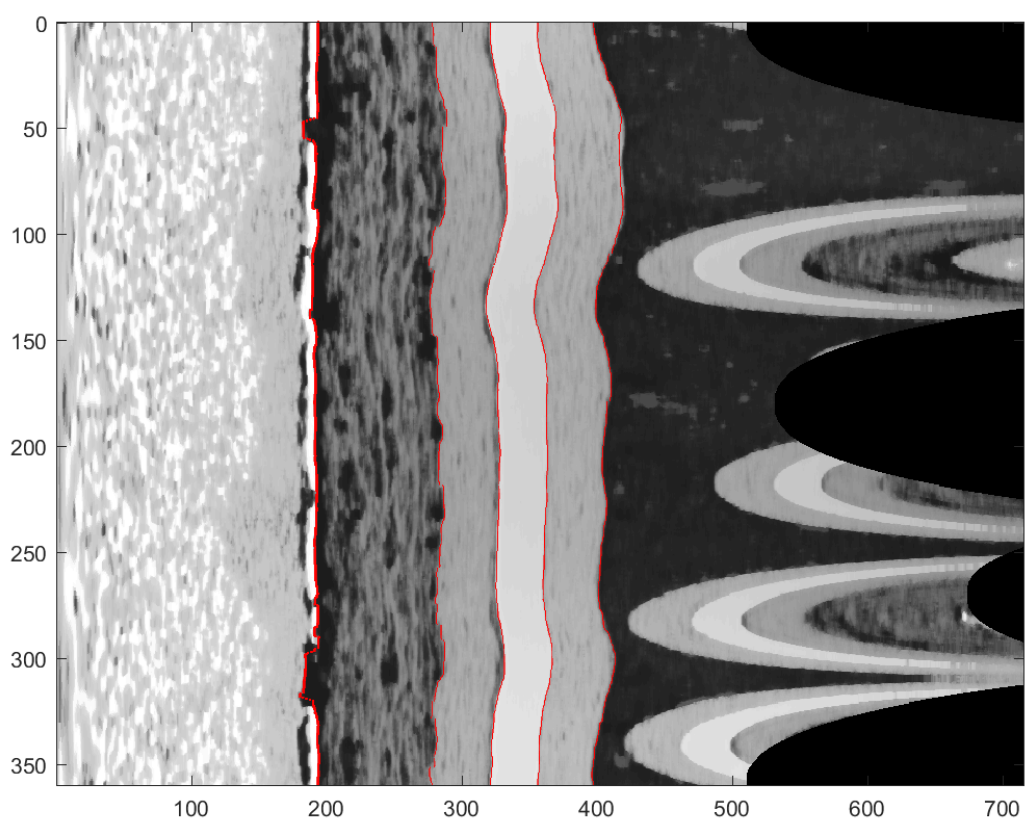
**P16082301N172 unwrapped**



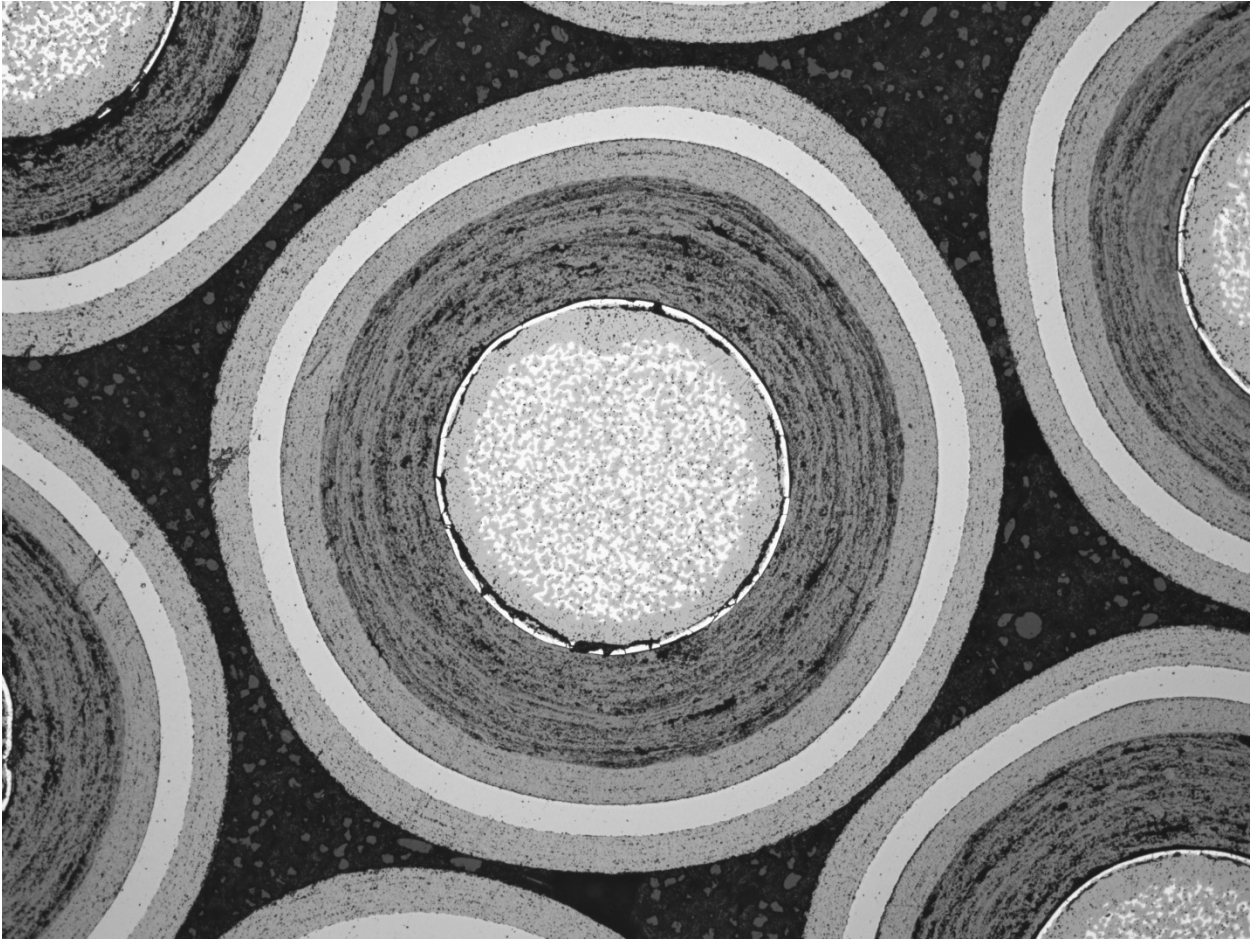


P16082301N174

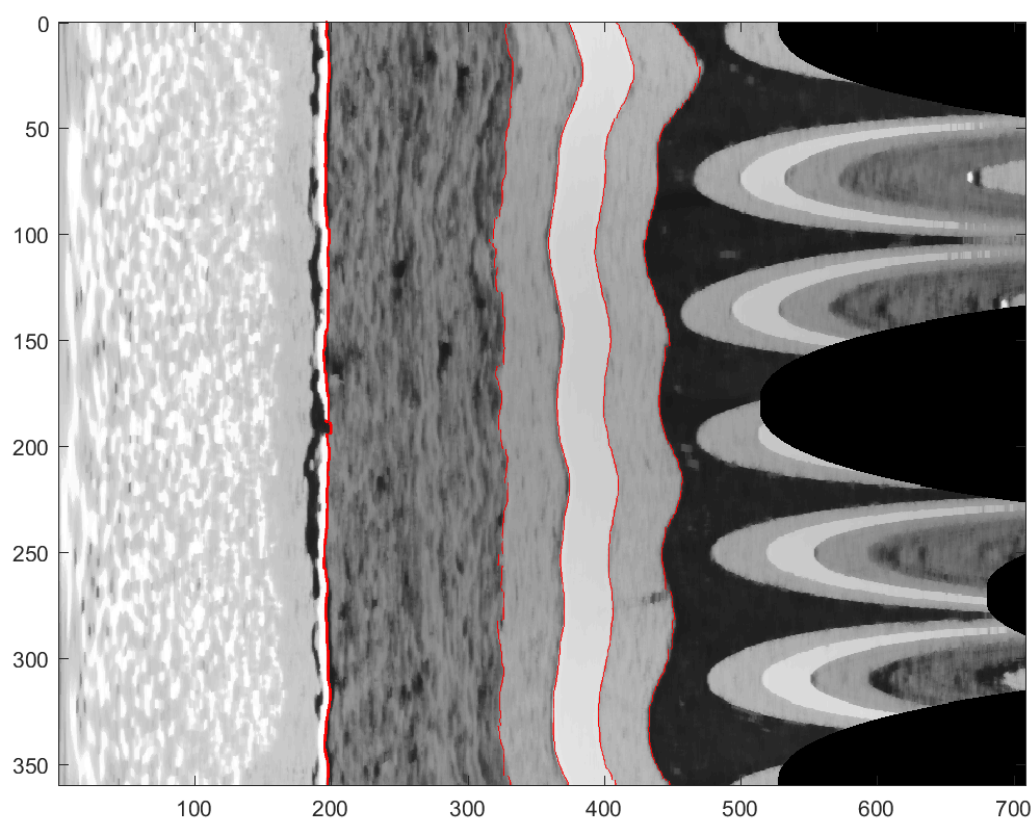




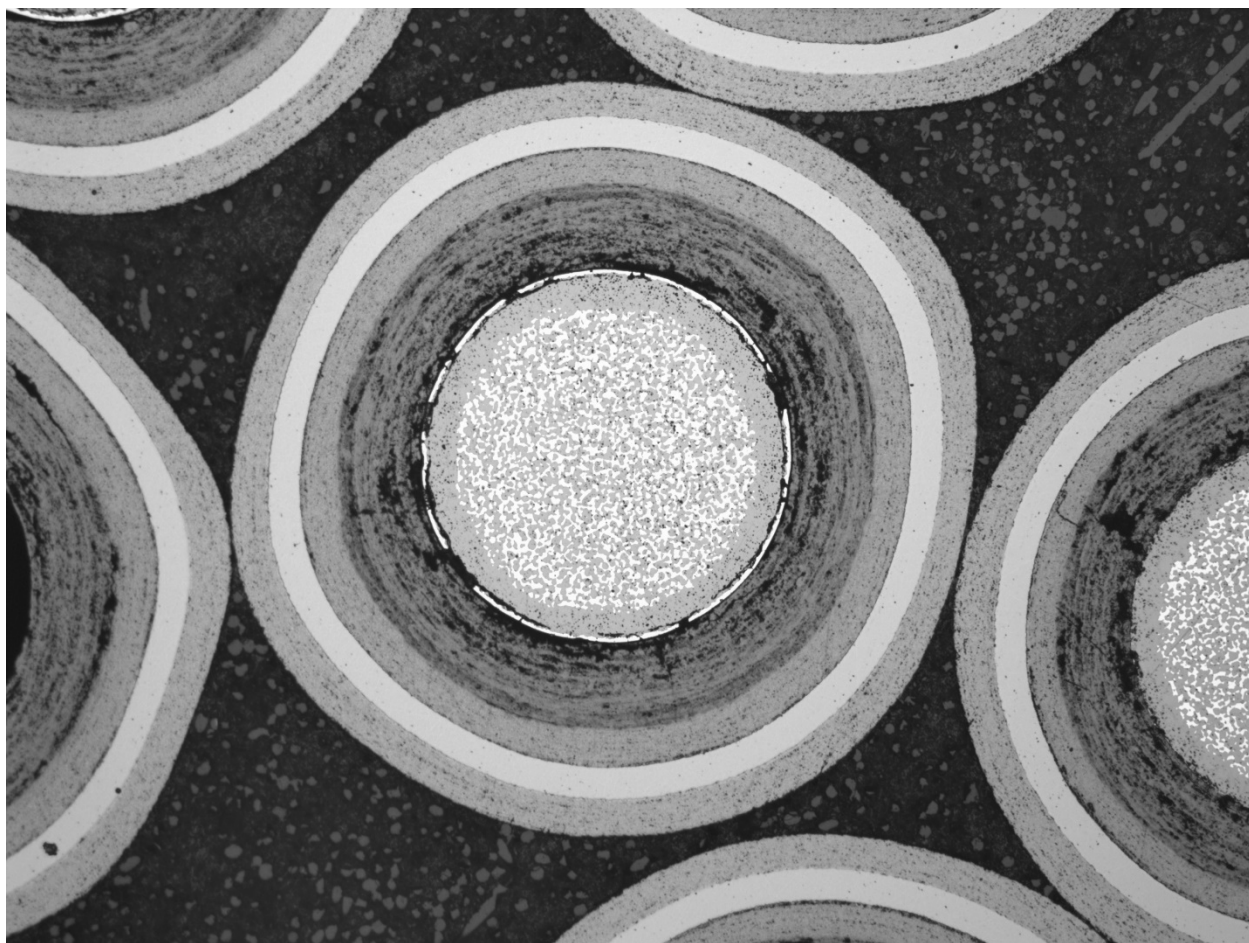
**P16082301N174 unwrapped**



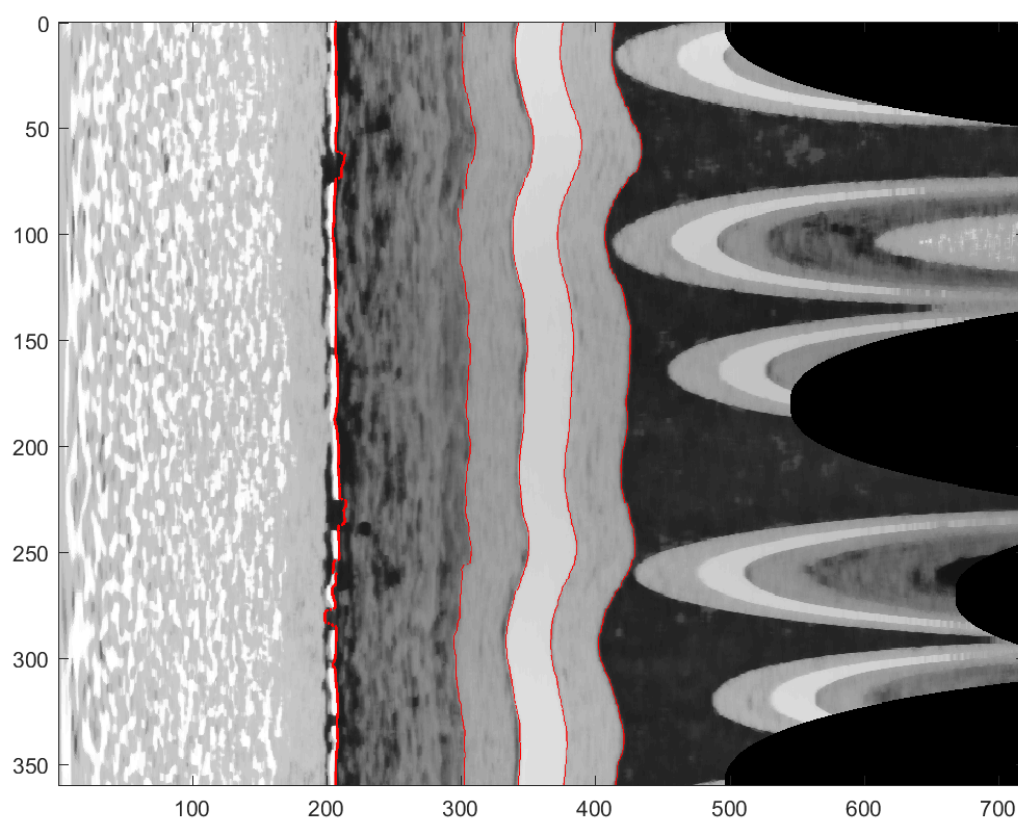
P16082301N175



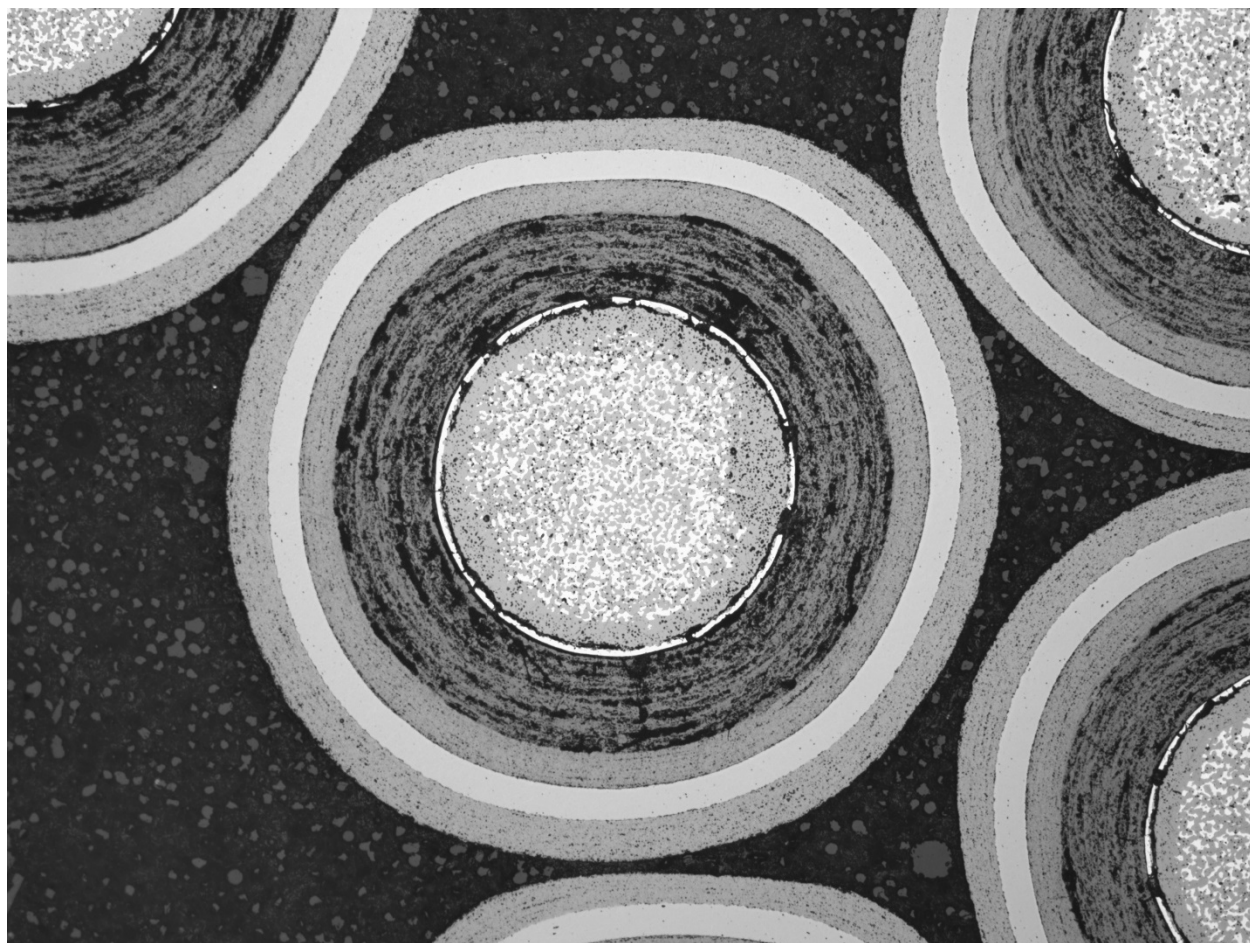
**P16082301N175 unwrapped**



P16082301N176

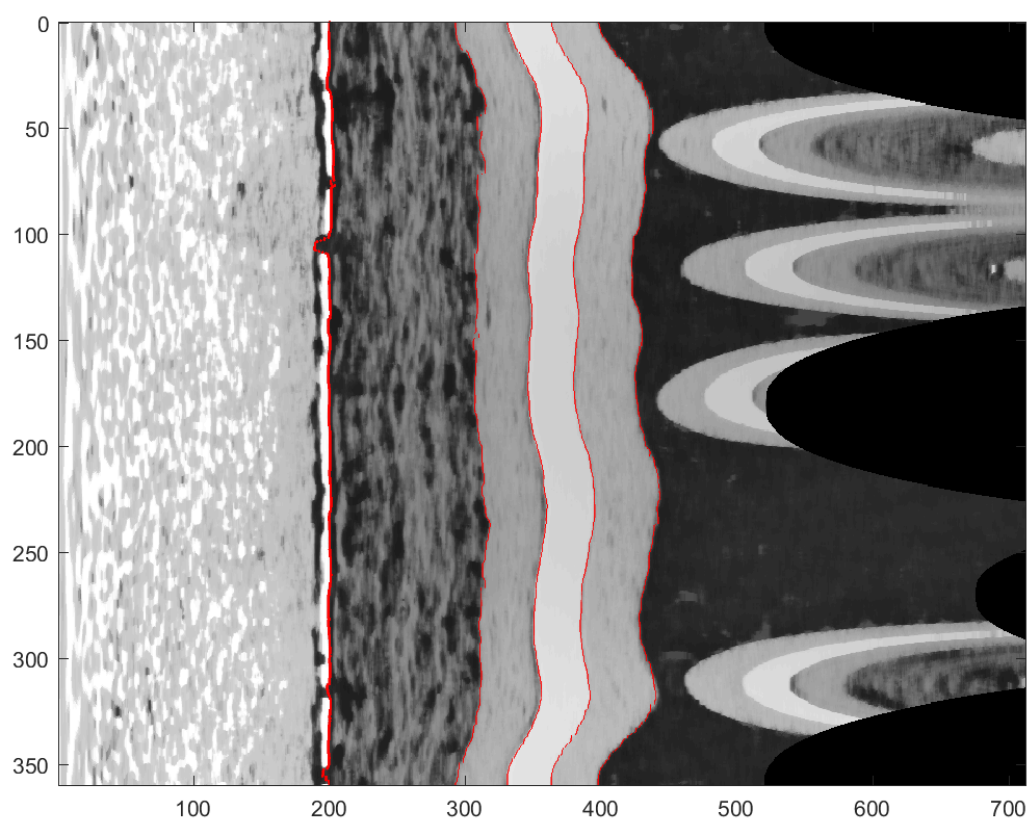


**P16082301N176 unwrapped**



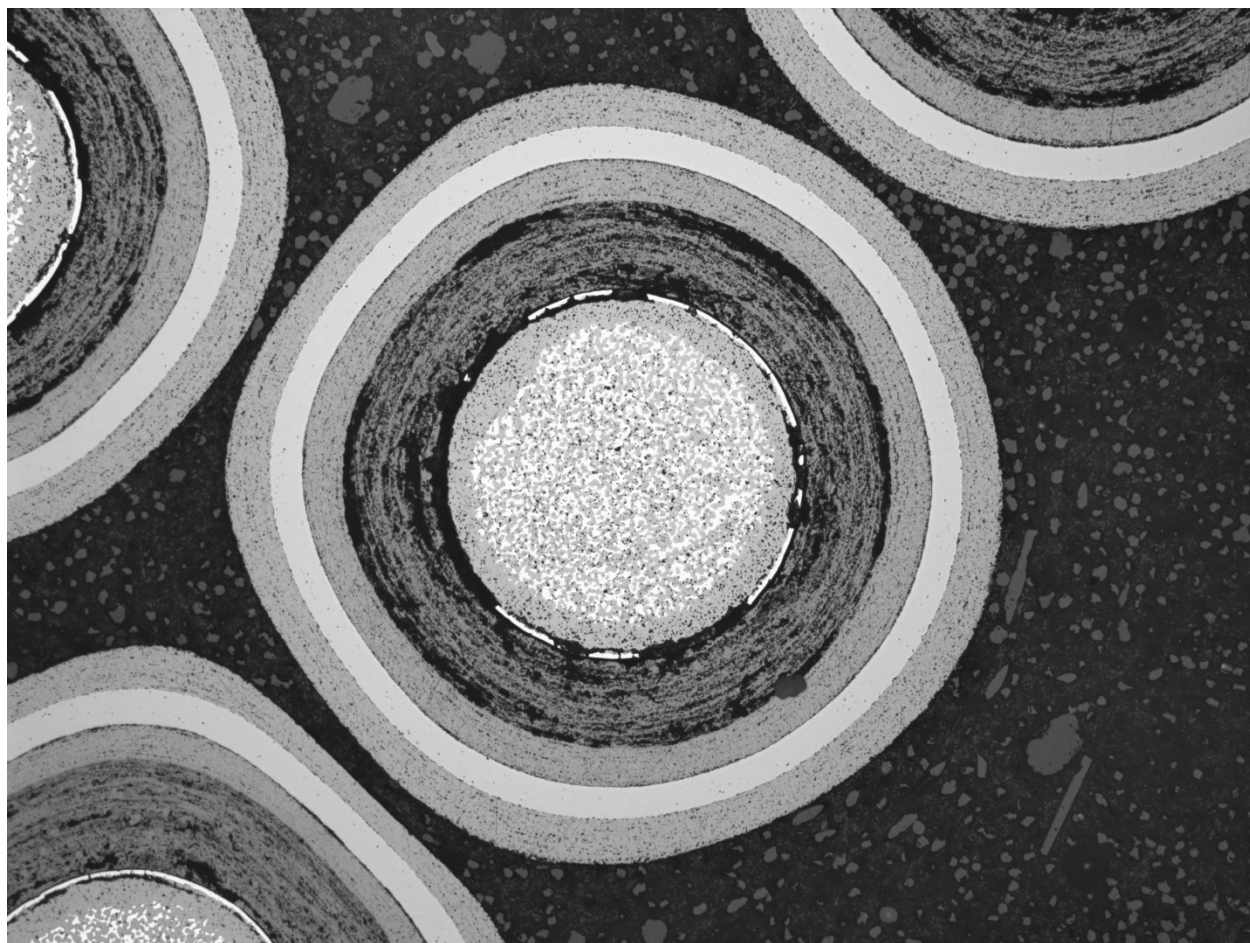
P16082301N178



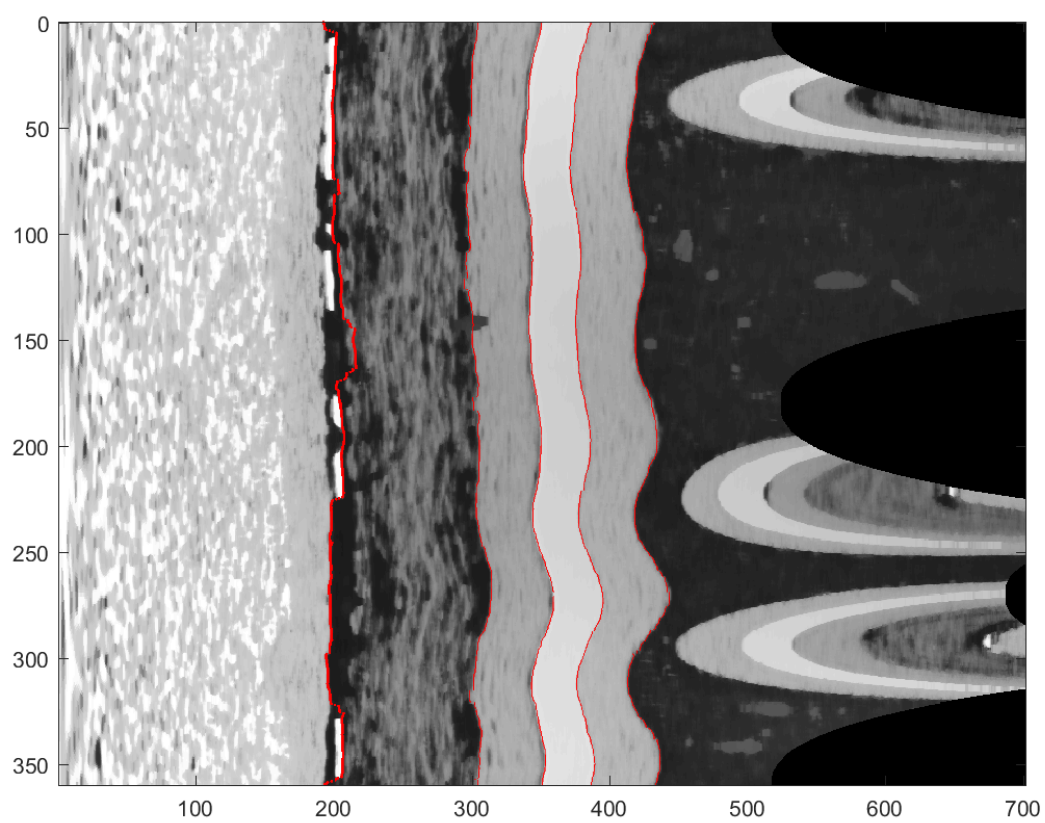


**P16082301N178 unwrapped**

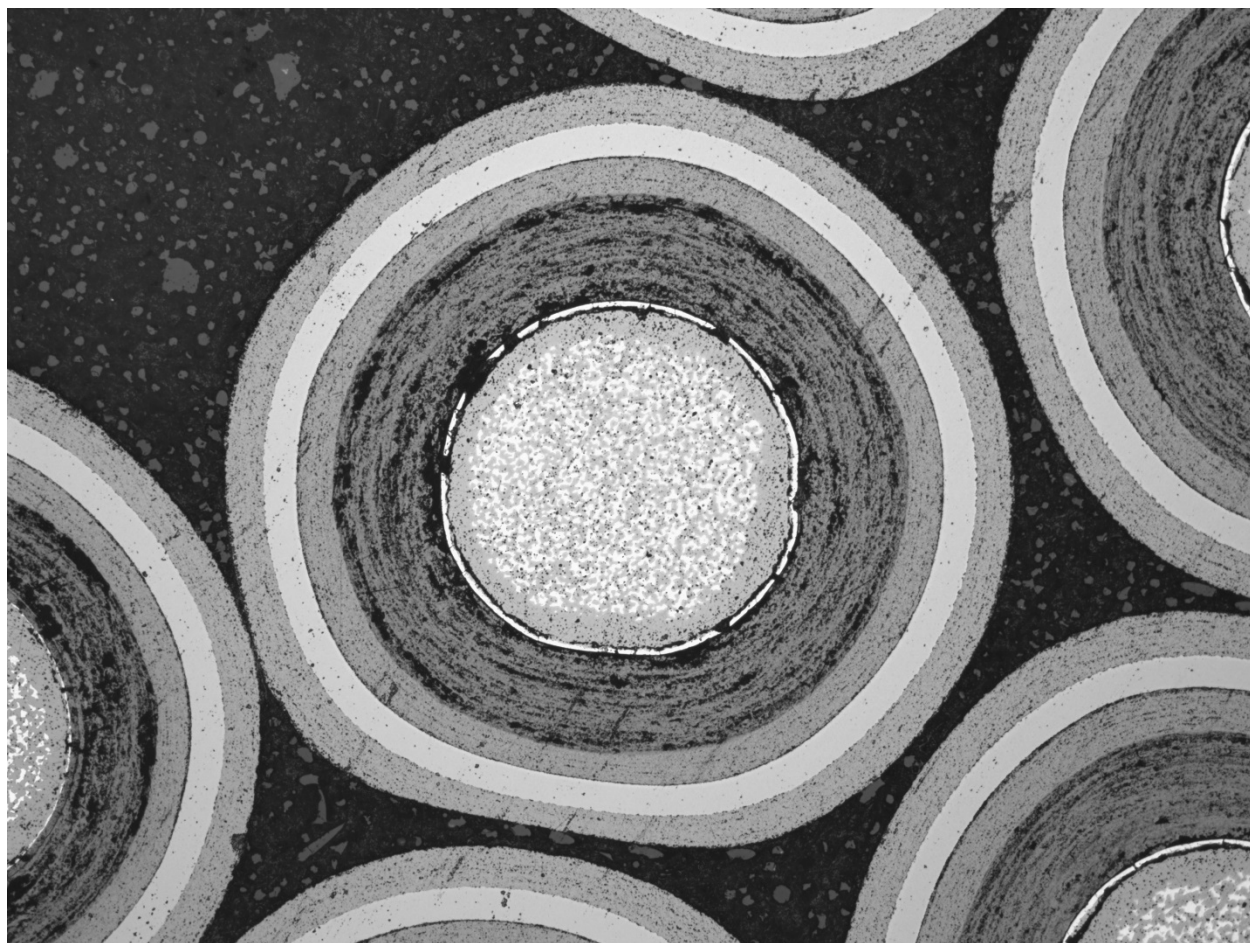




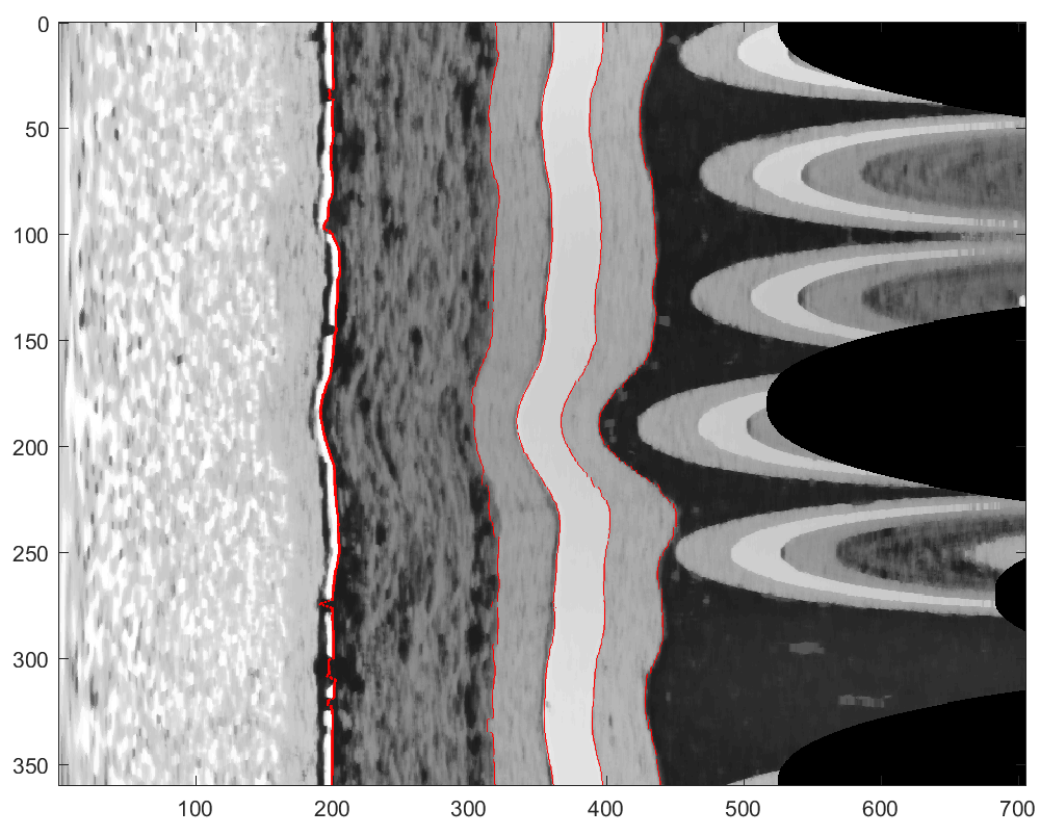
P16082301N179



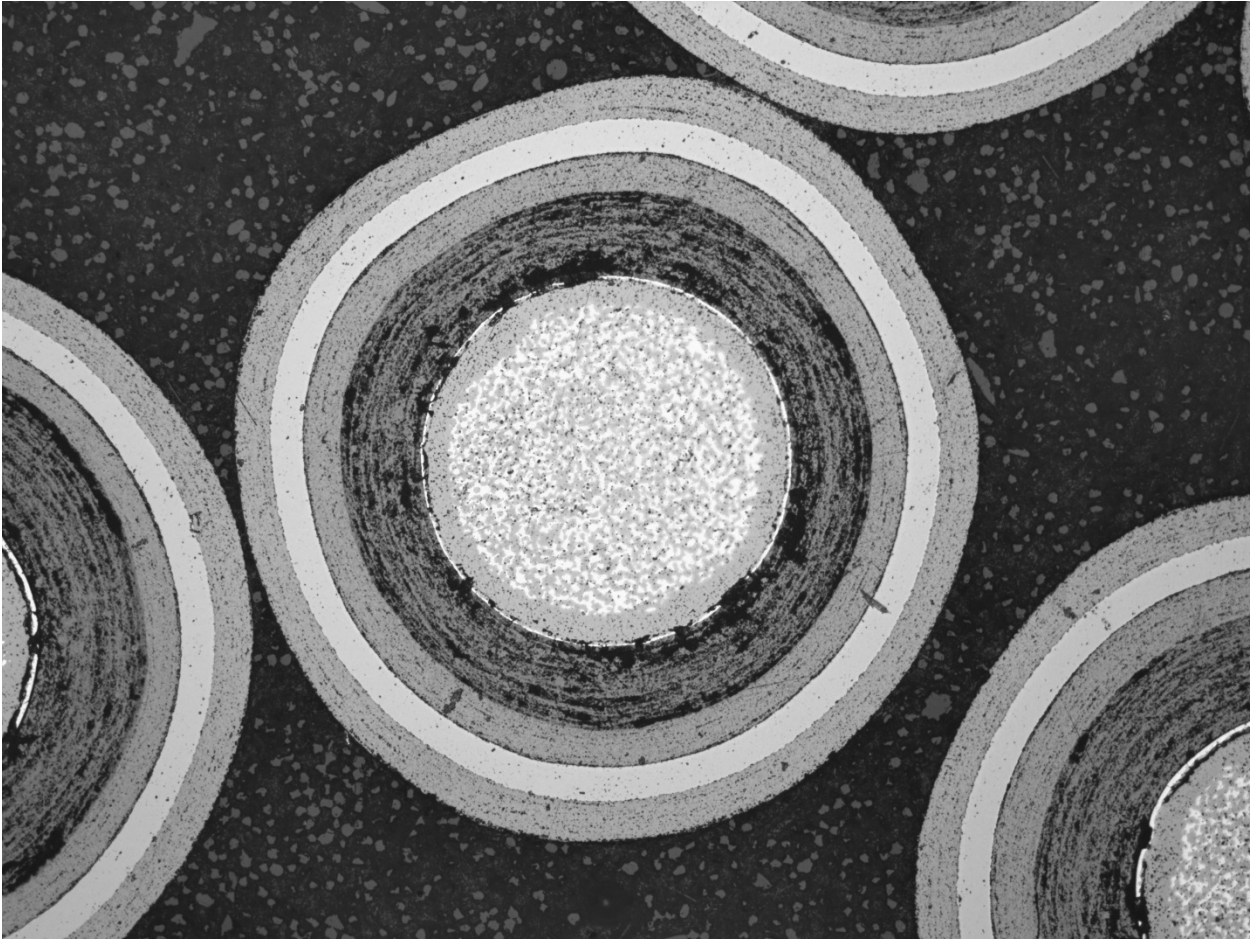
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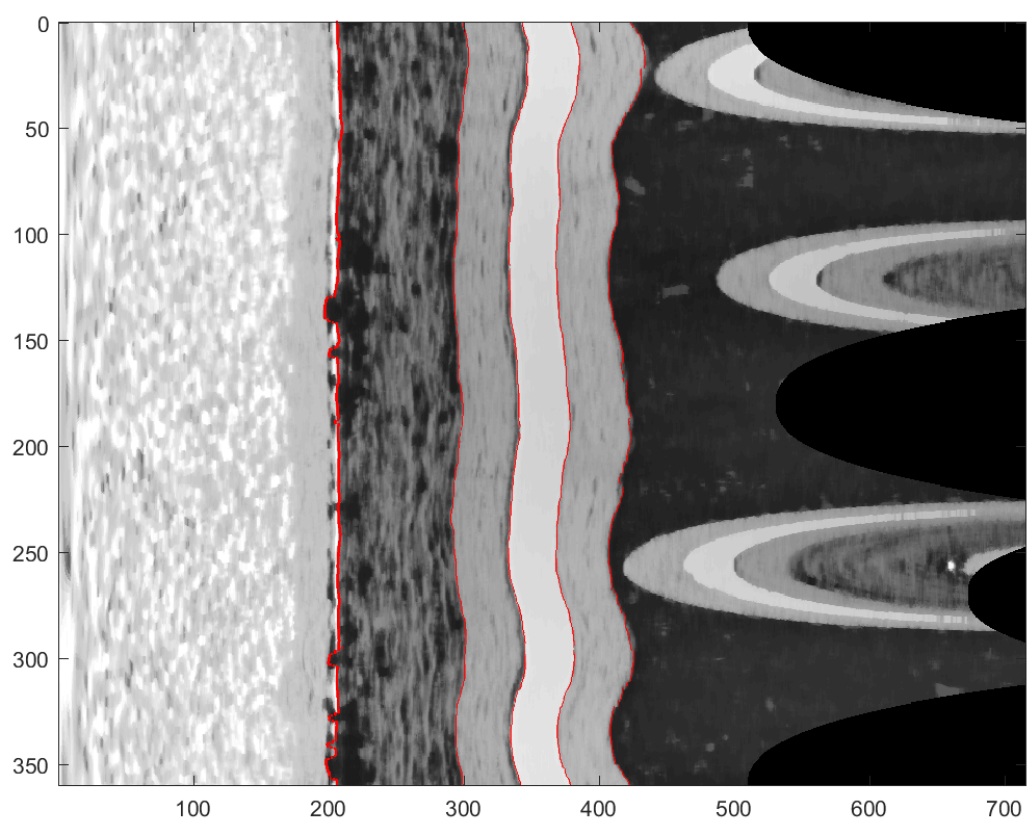
P16082301N181



**P16082301N181 unwrapped**

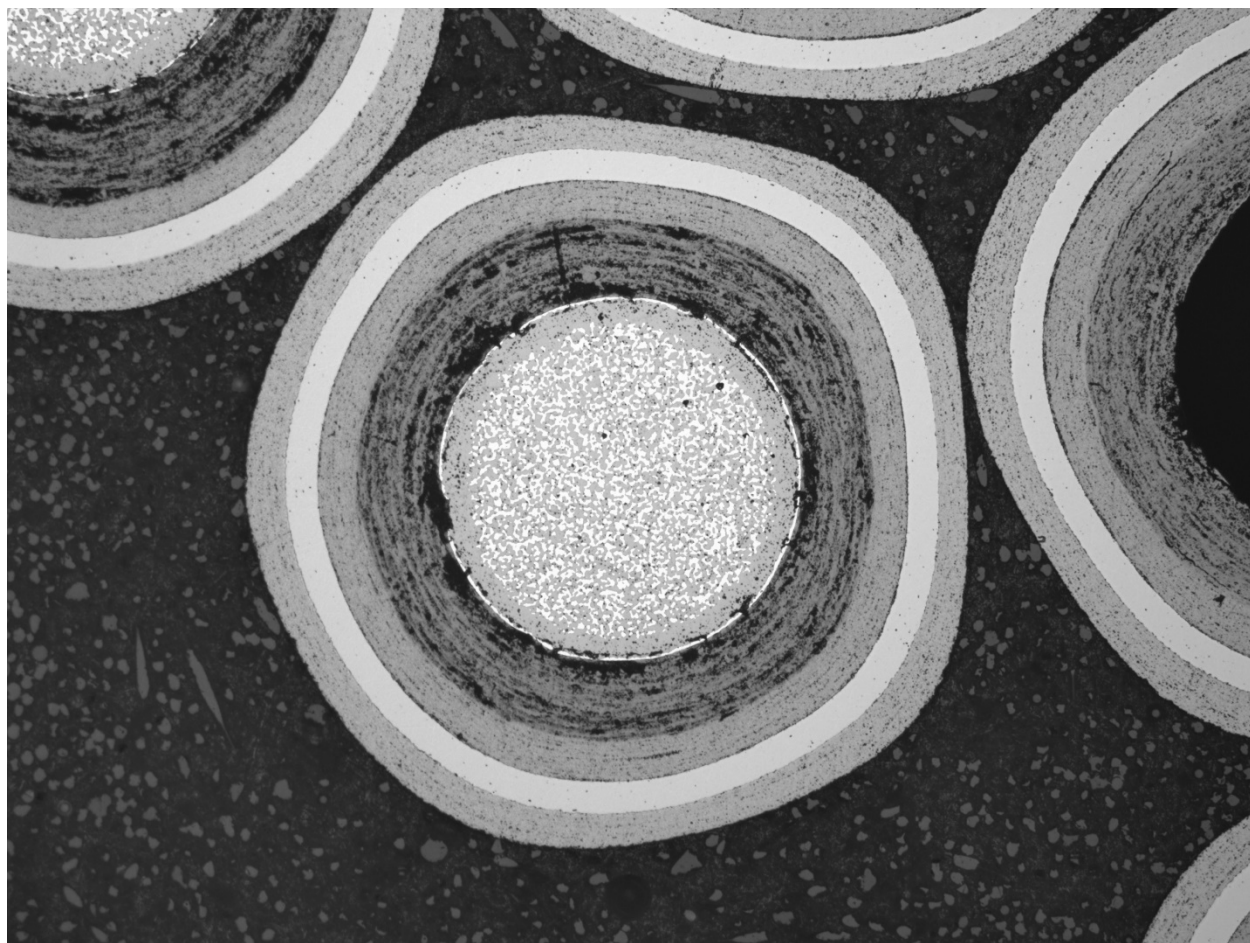


P16082301N182

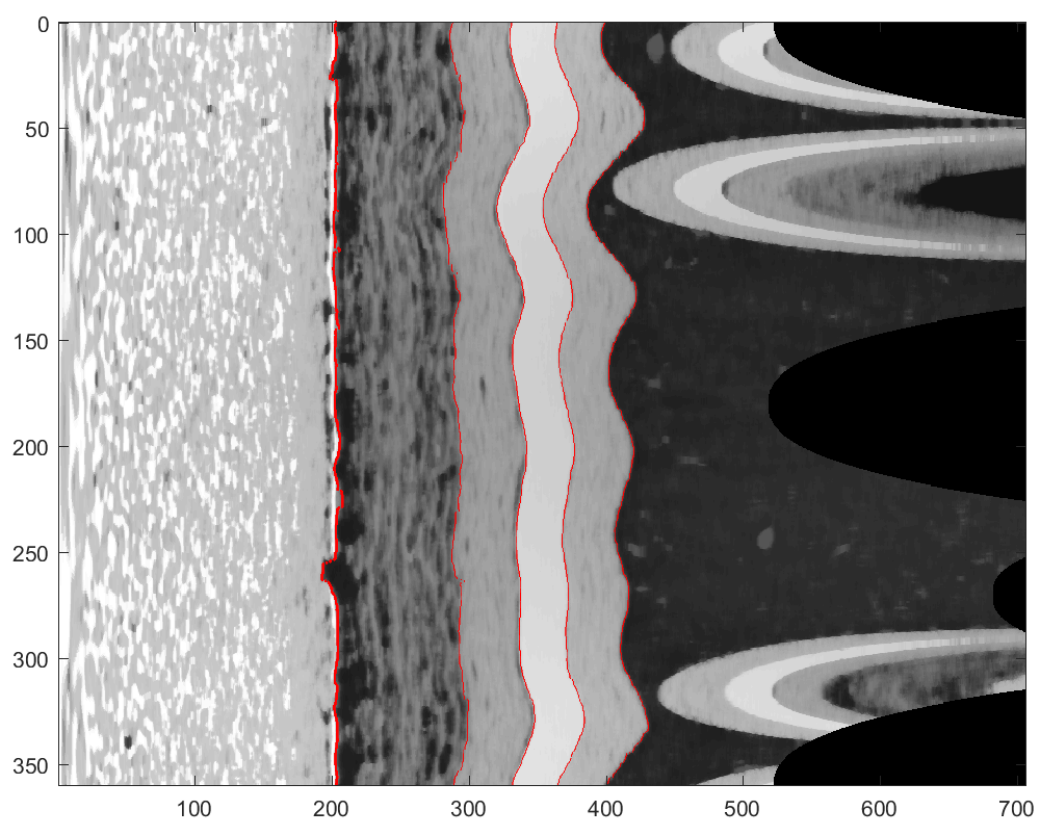


**P16082301N182 unwrapped**

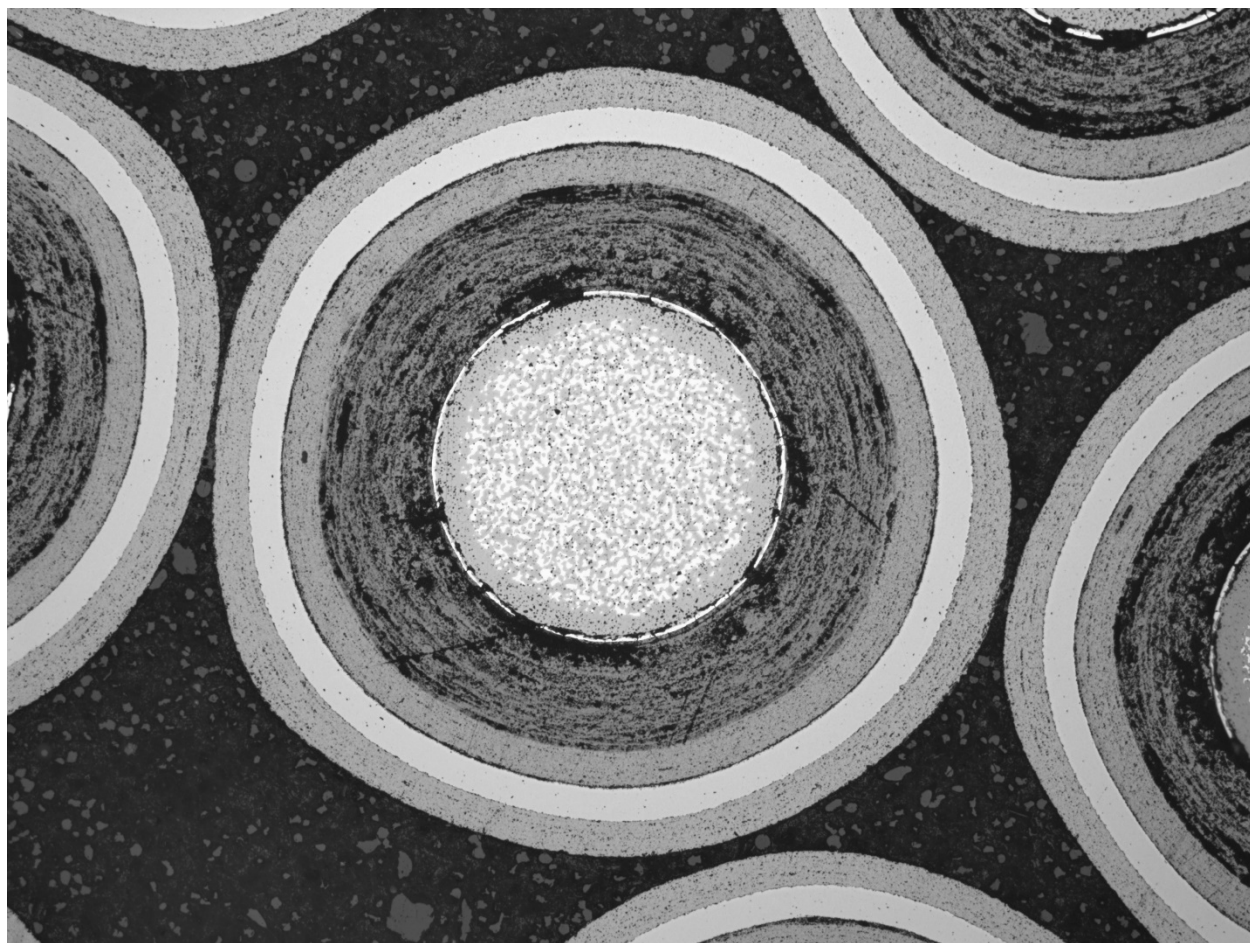




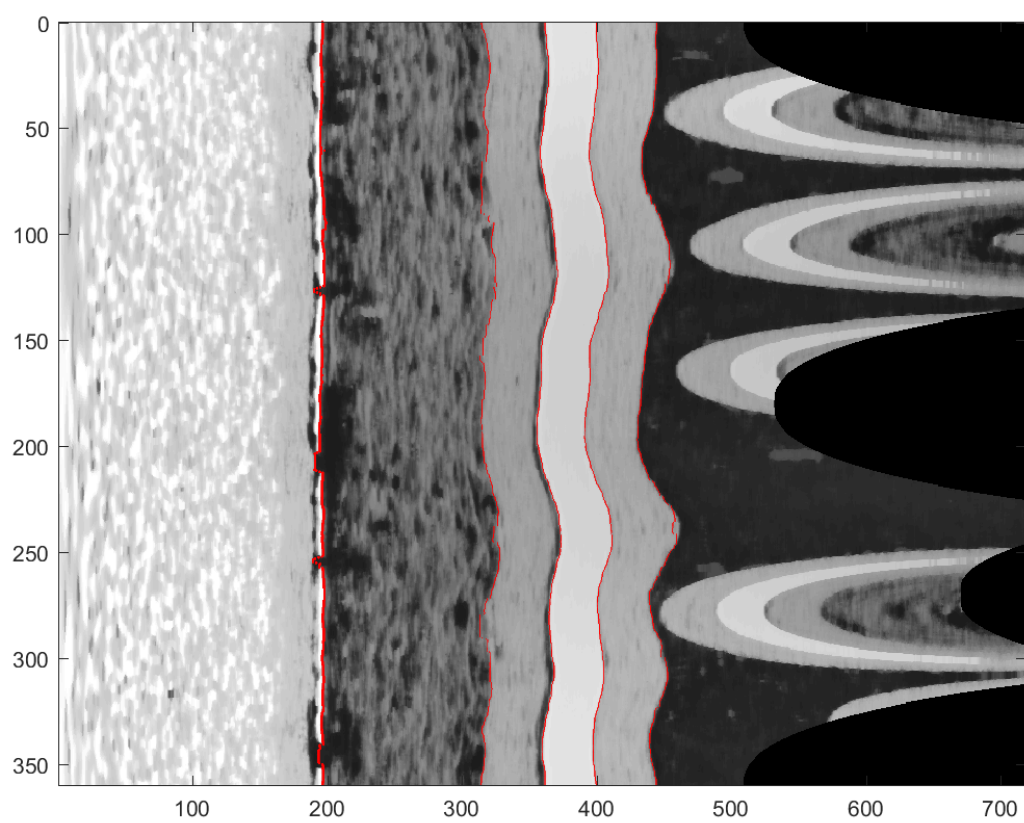
P16082301N183



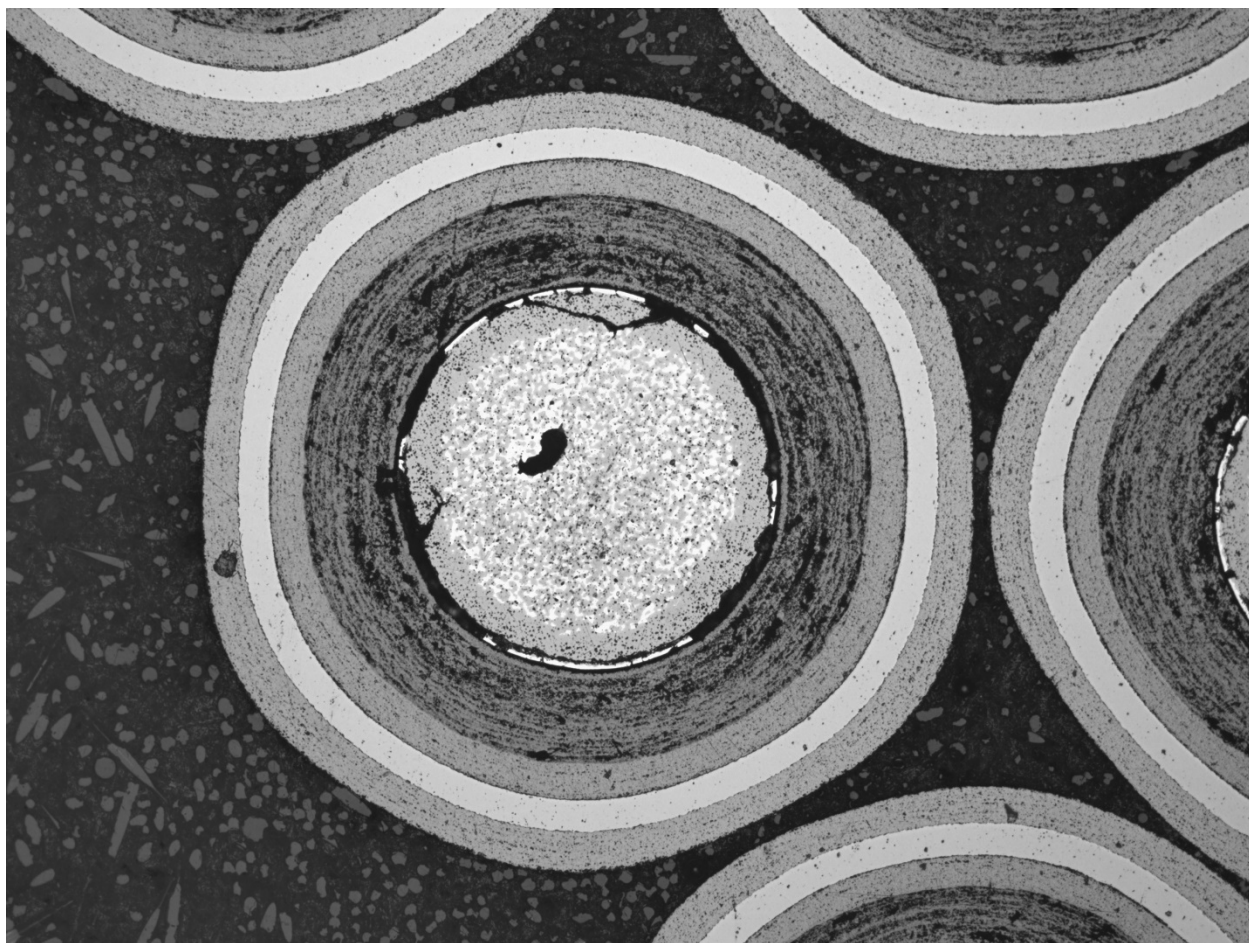
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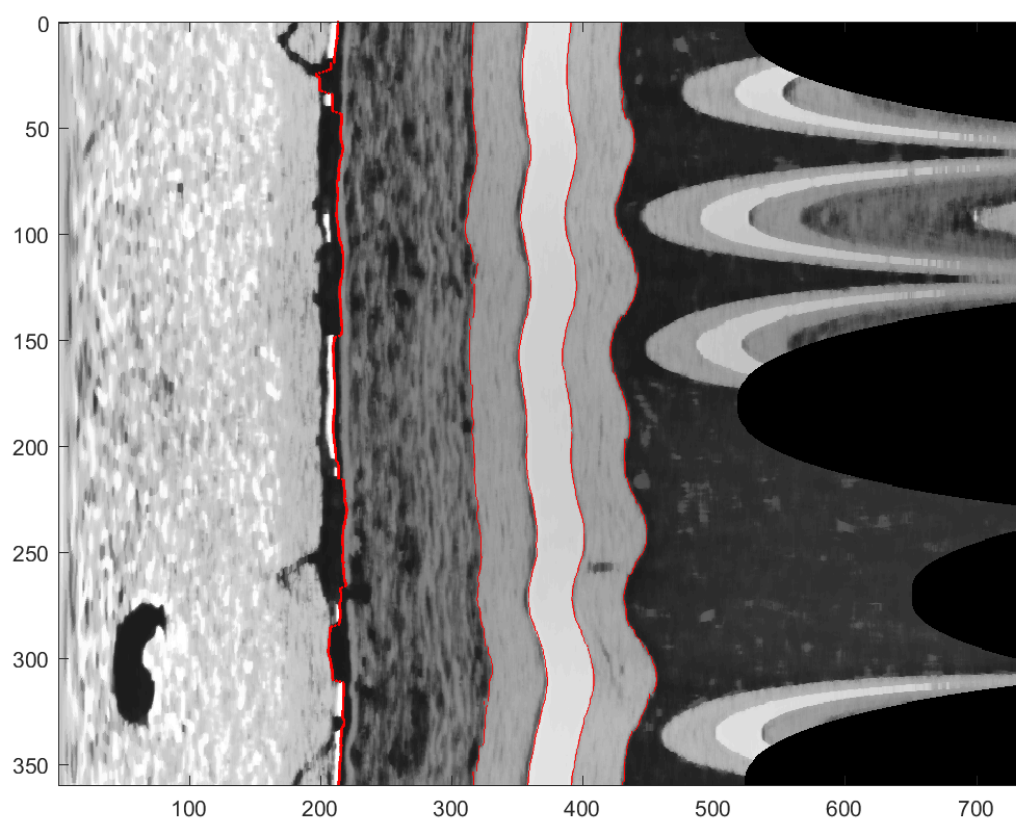
P16082301N185



**P16082301N185 unwrapped**

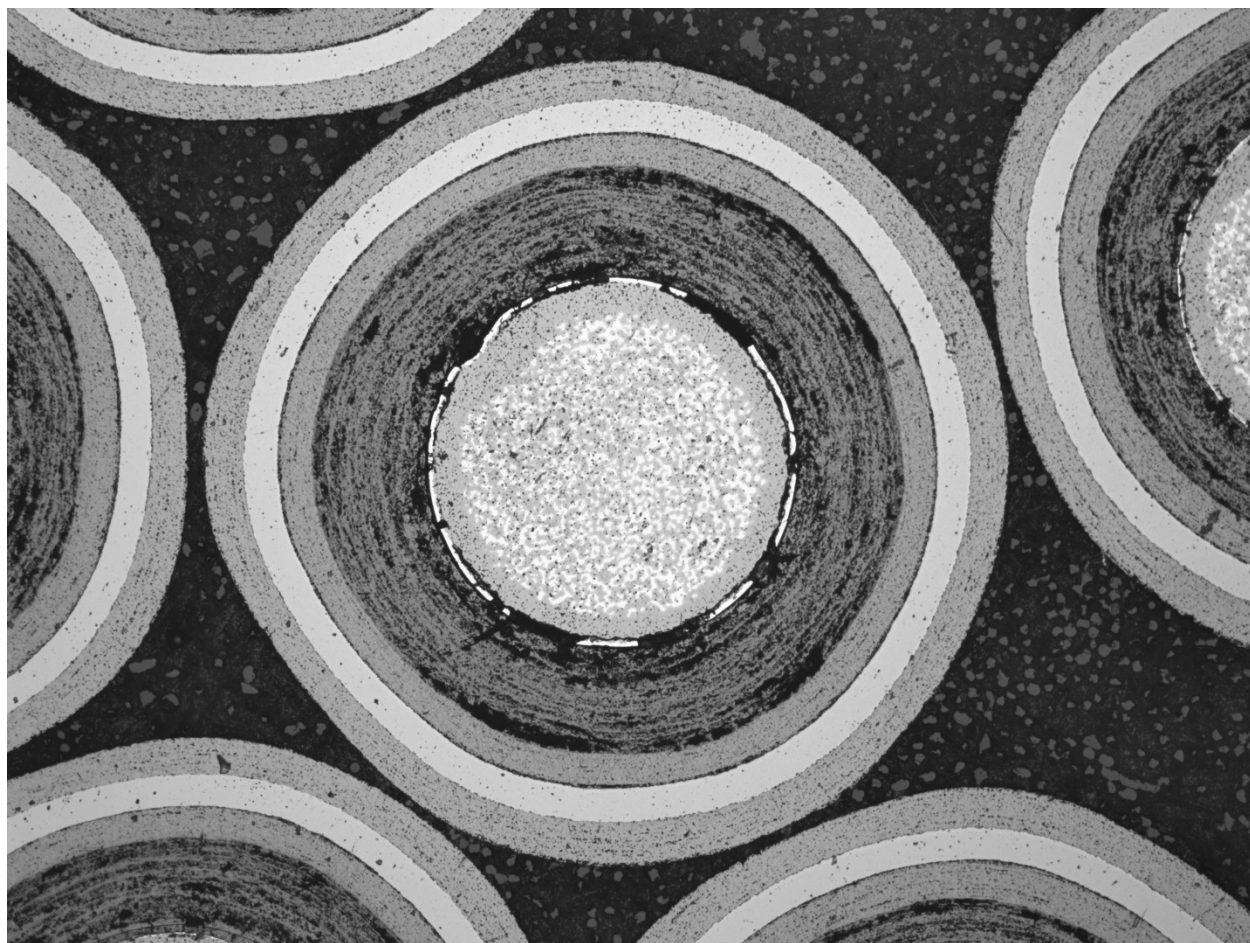


P16082301N186

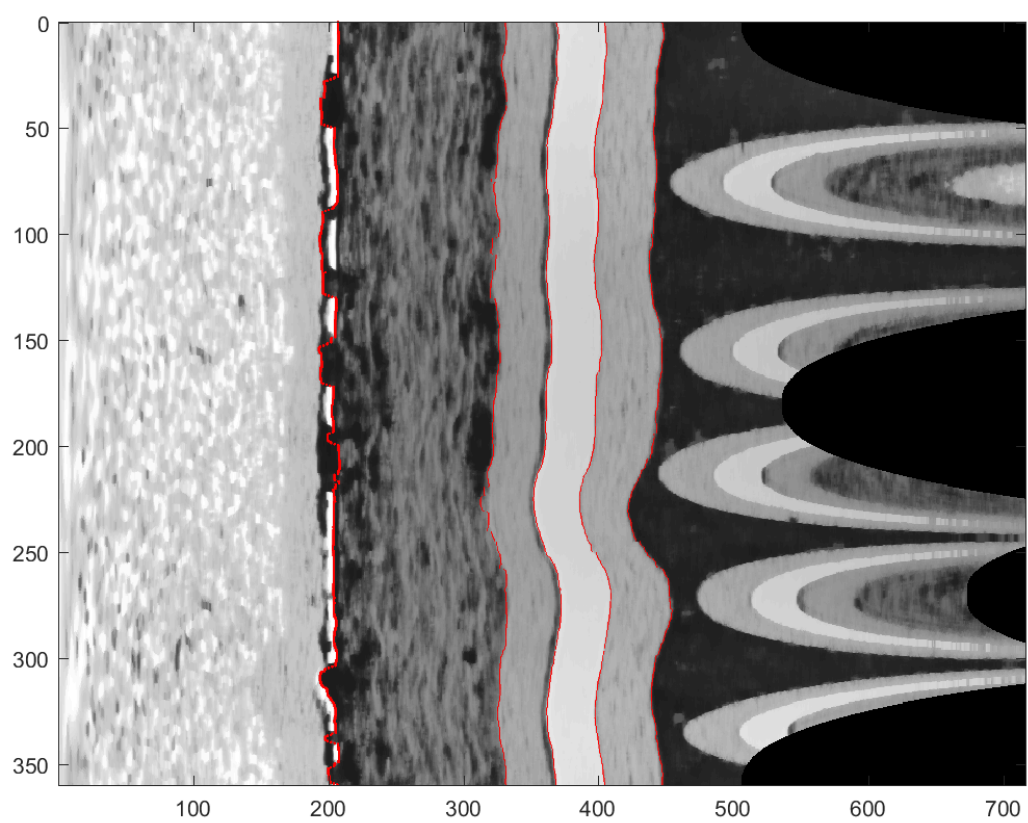


**P16082301N186 unwrapped**

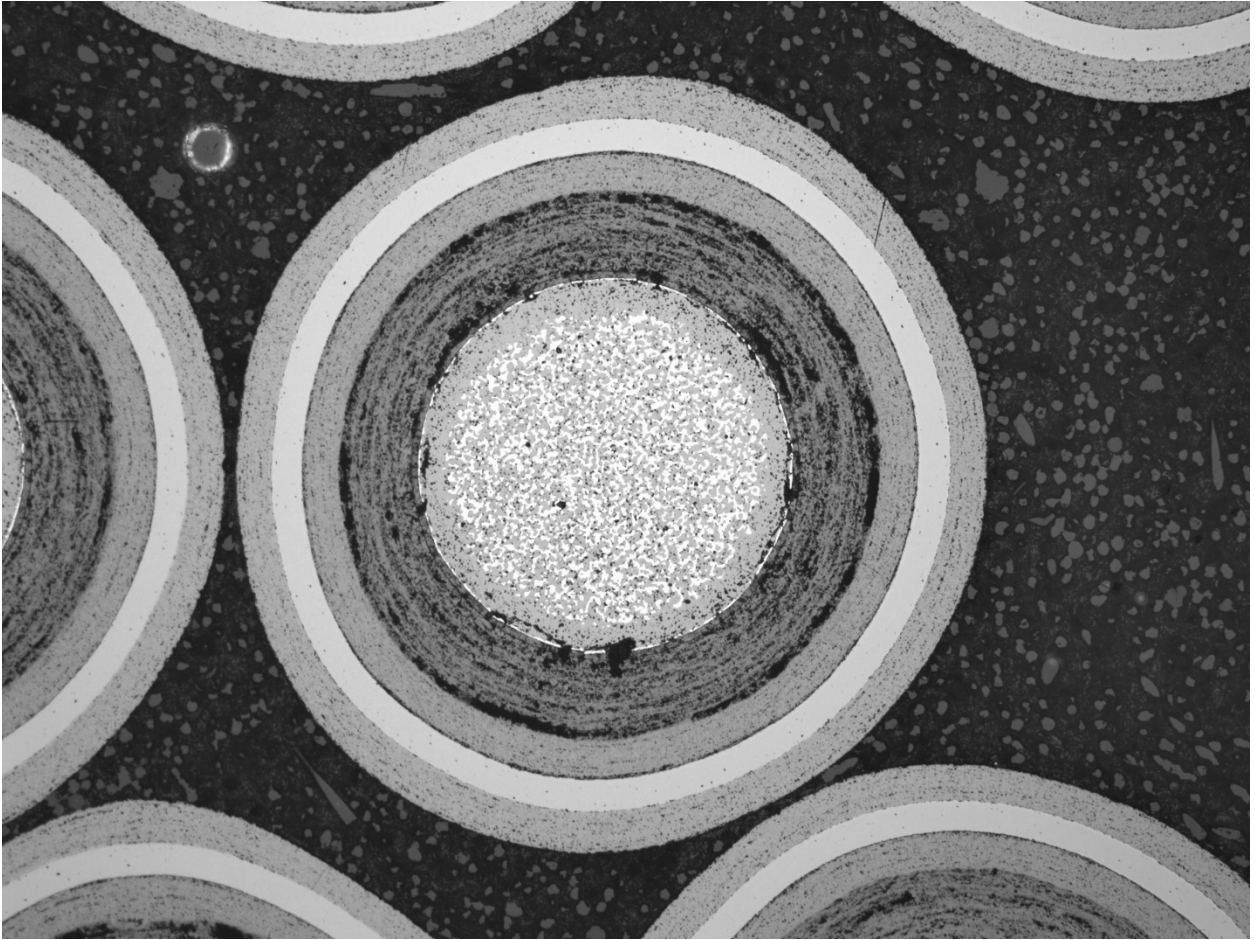




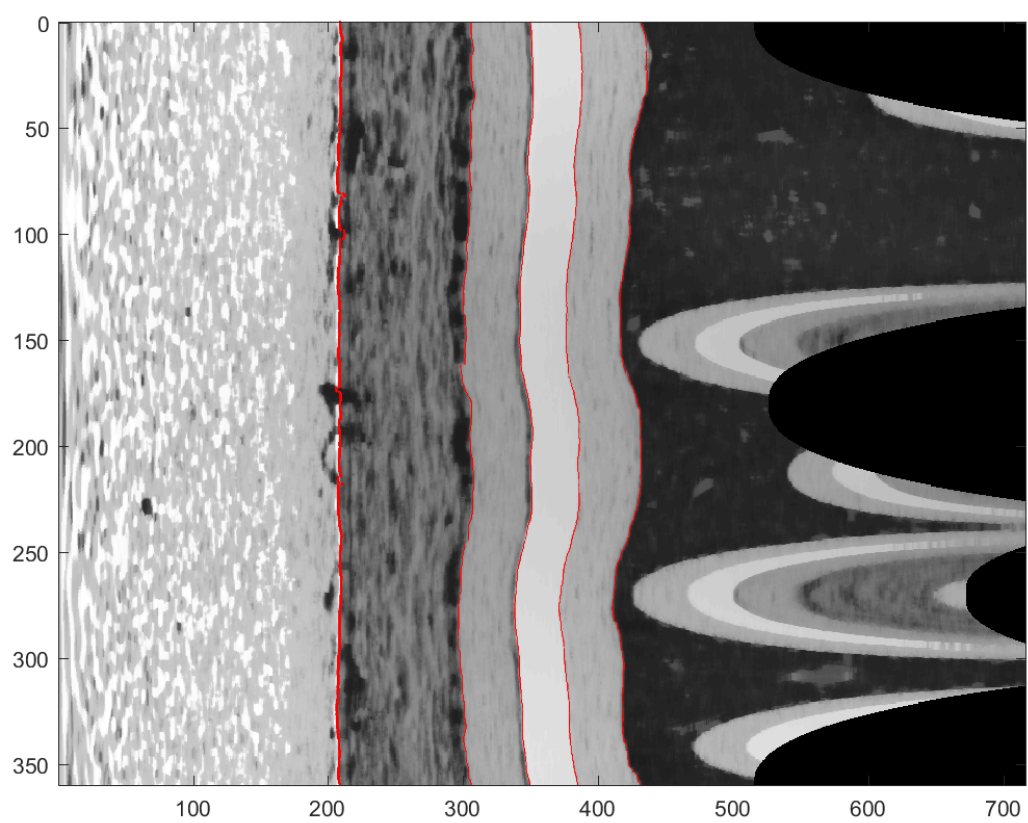
P16082301N187



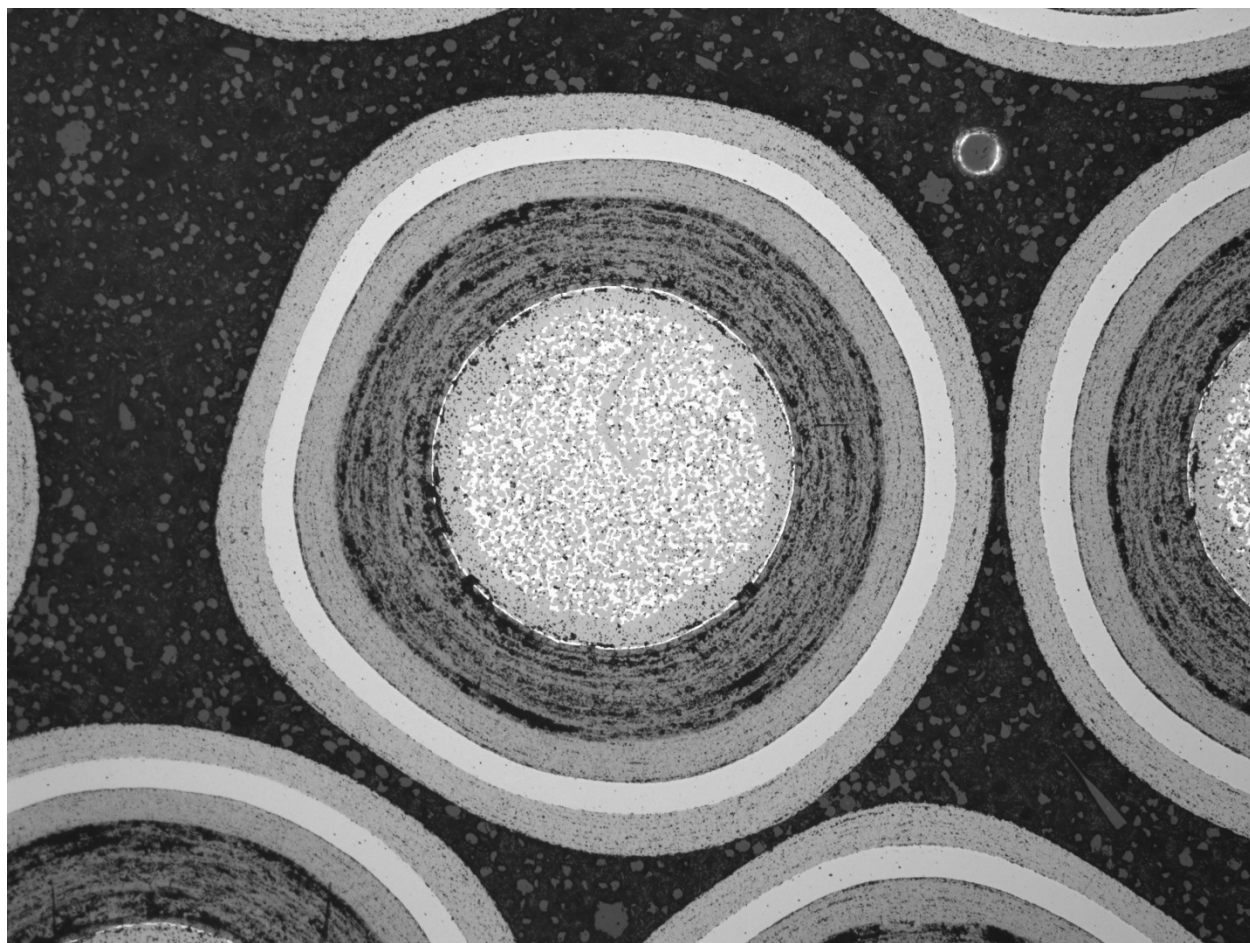
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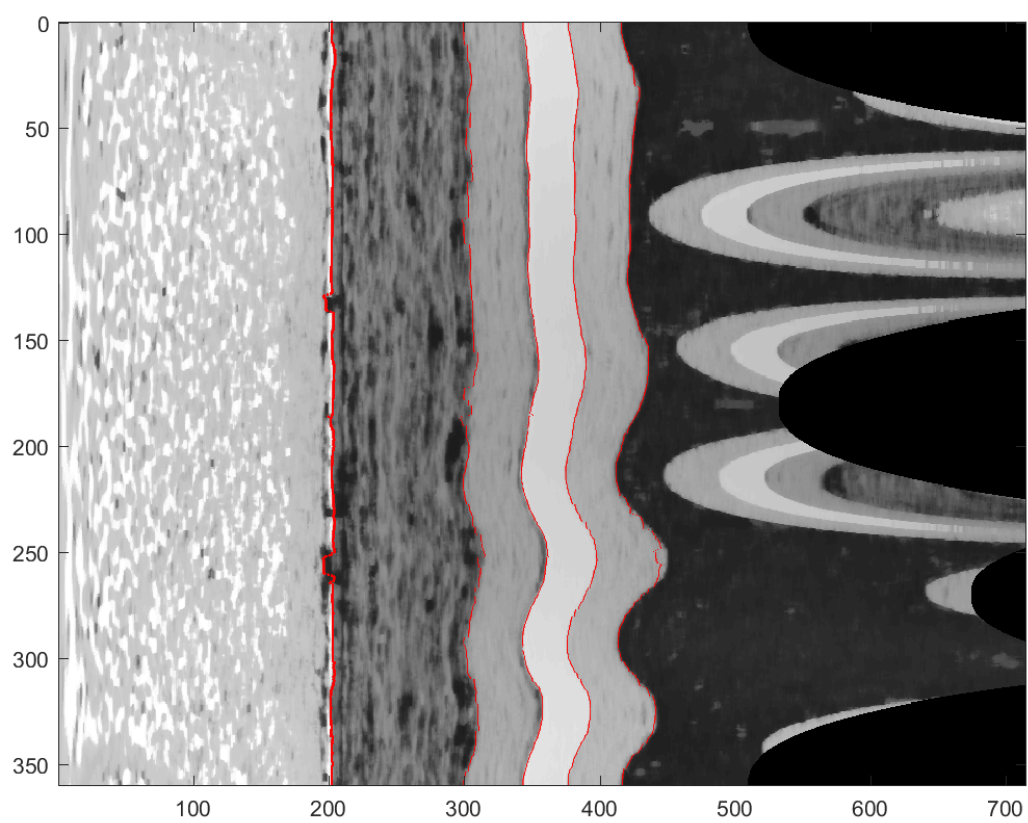
P16082301N188



**P16082301N188 unwrapped**

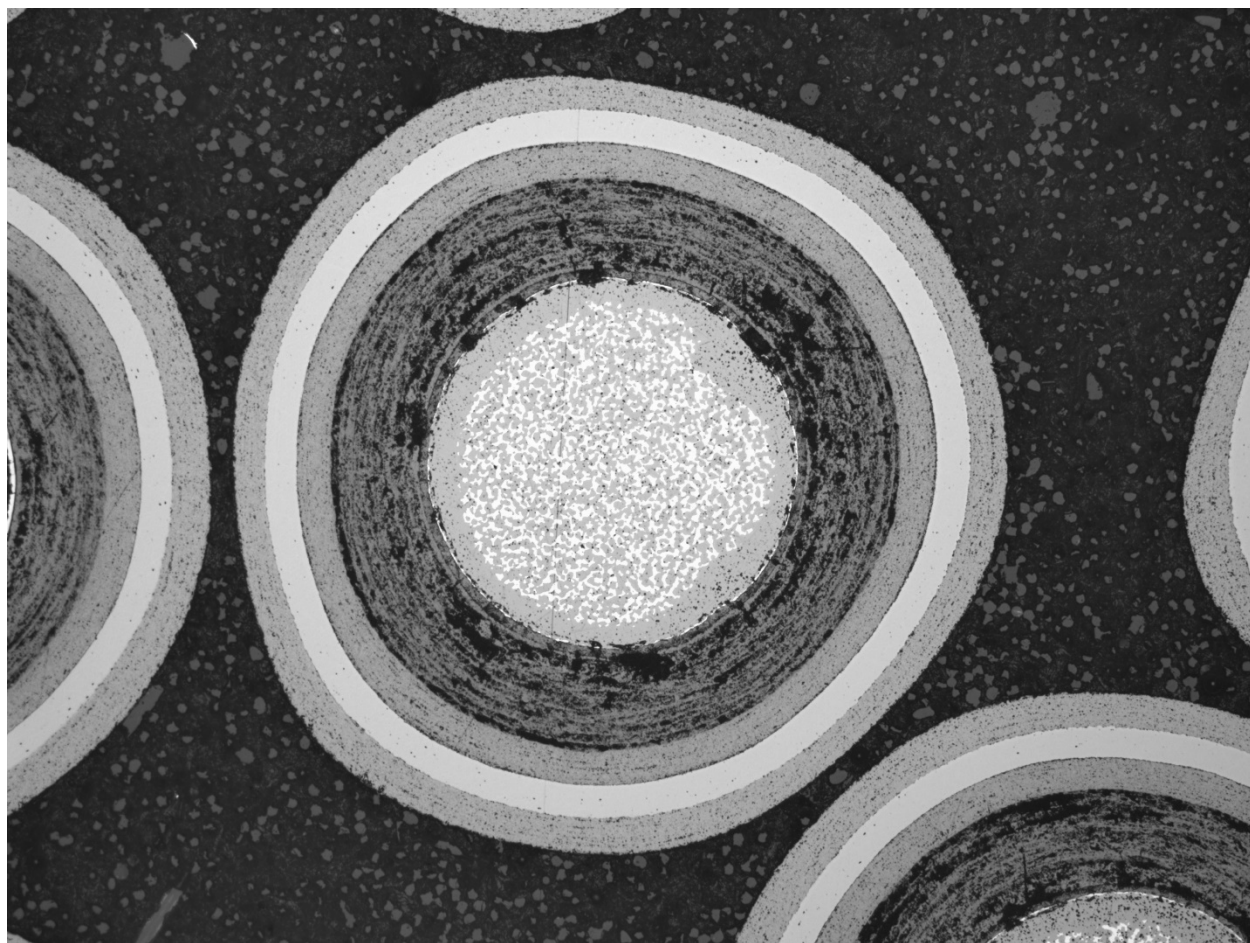


P16082301N189

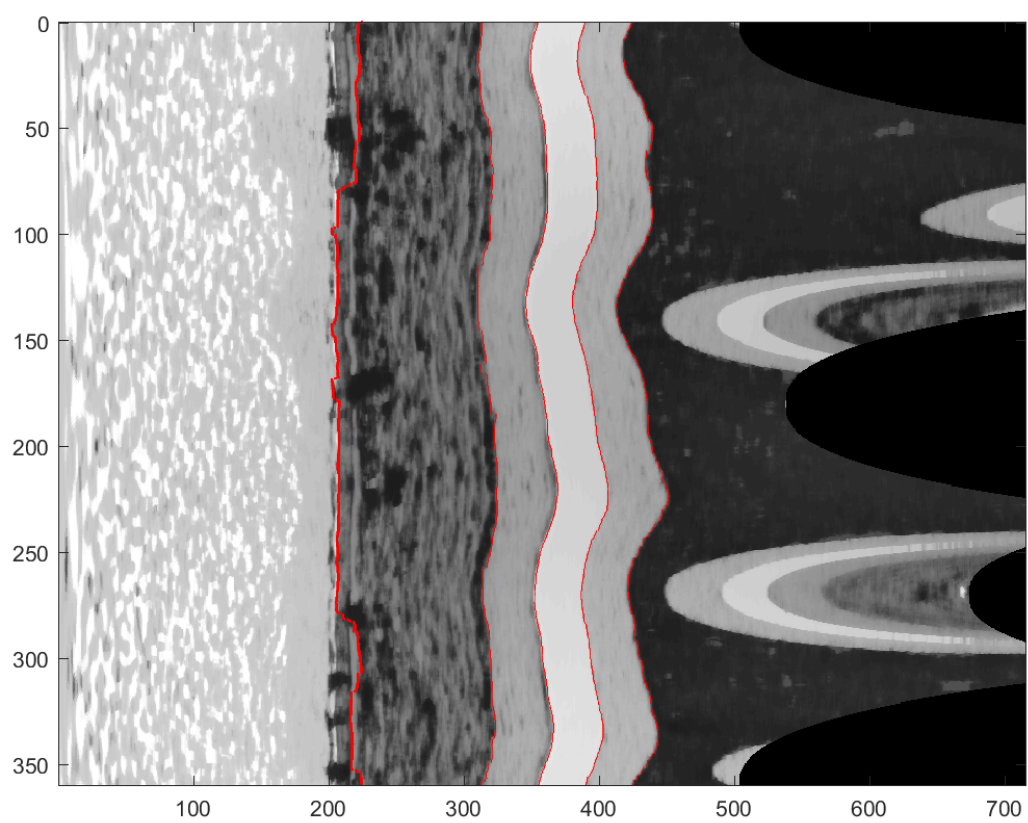


**P16082301N189 unwrapped**

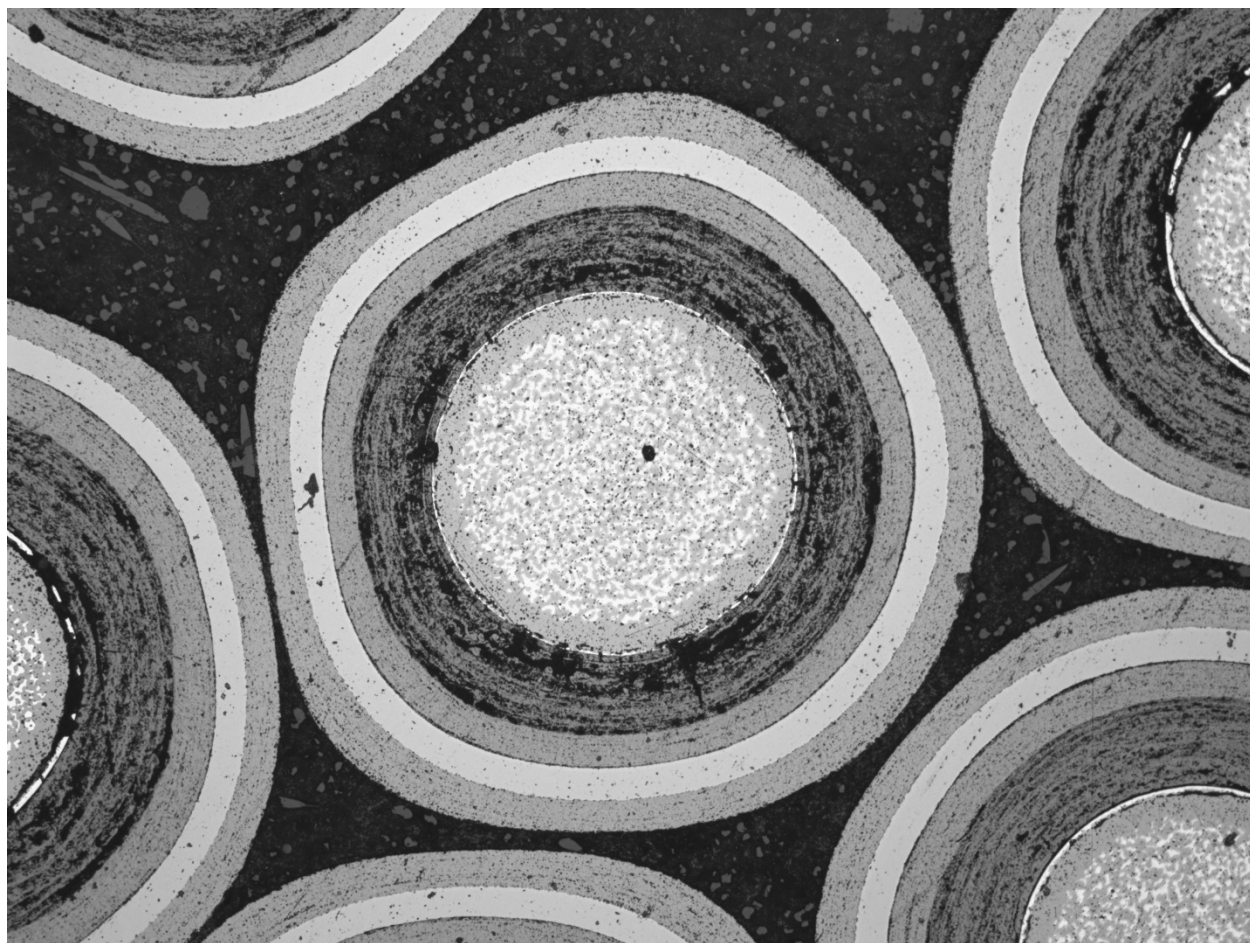




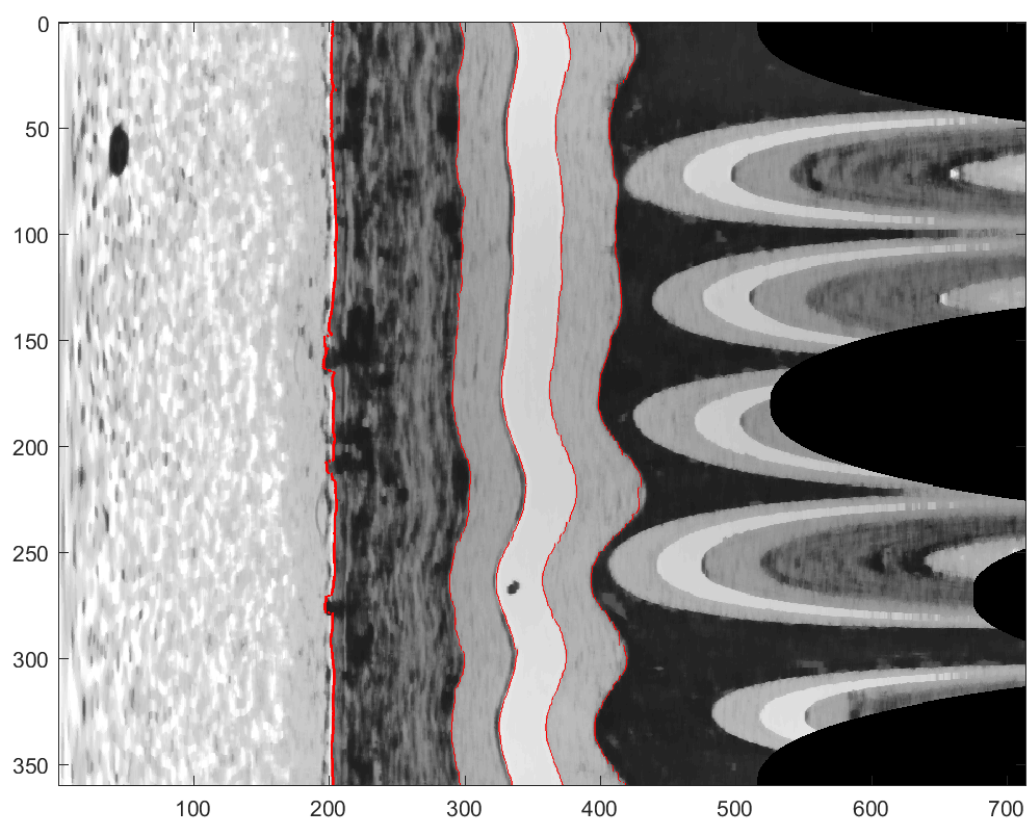
P16082301N190



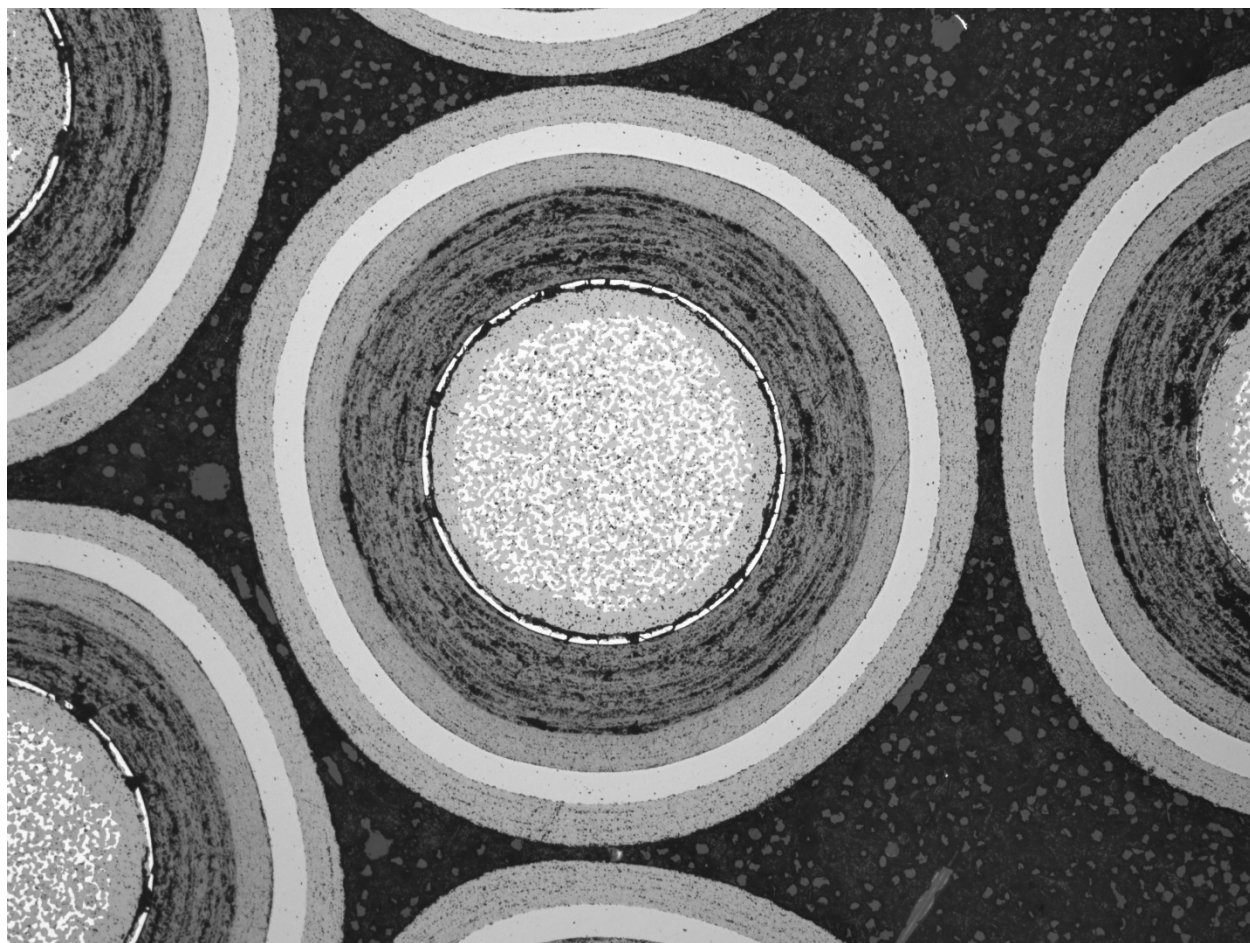
**P16082301N190 unwrapped**



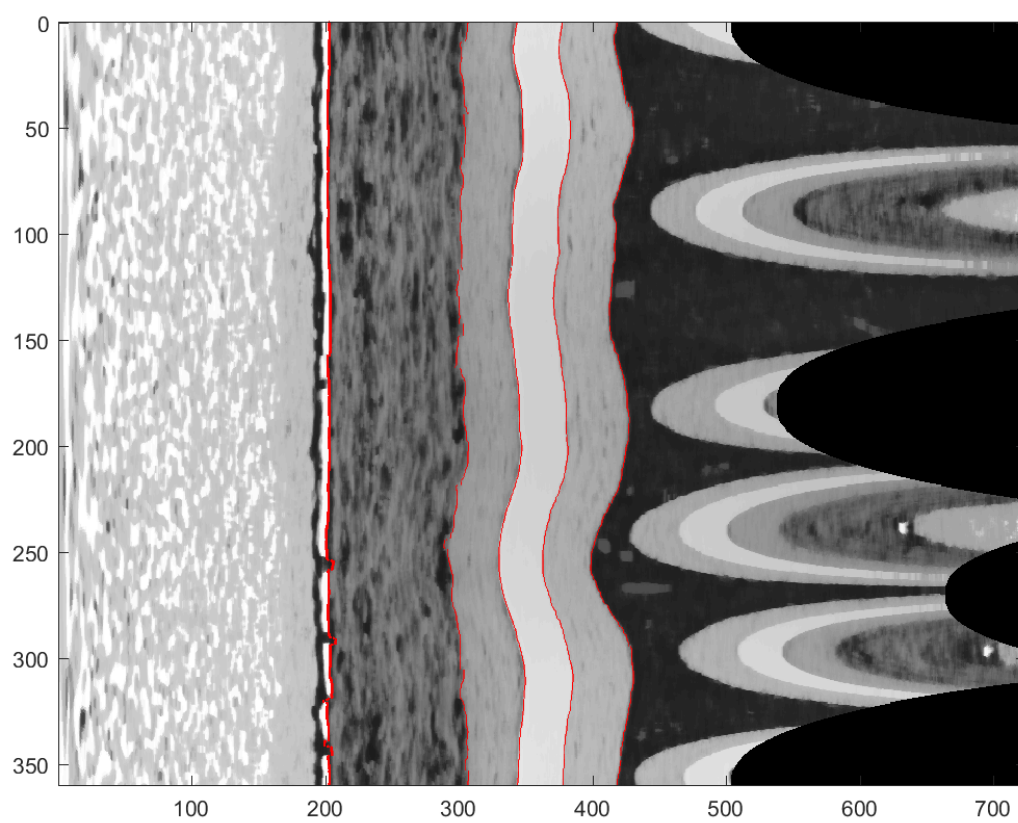
P16082301N191



**P16082301N191 unwrapped**

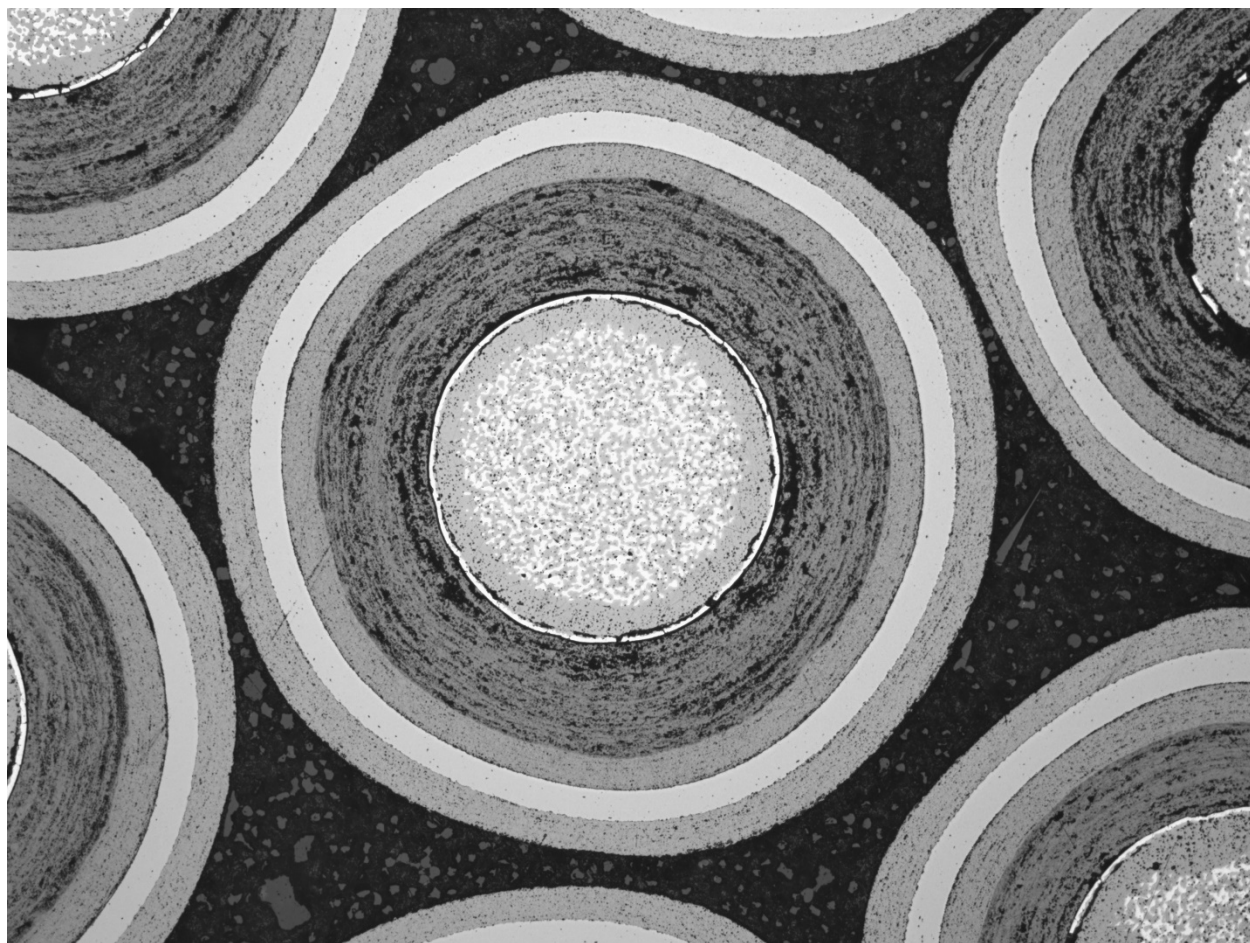


P16082301N192

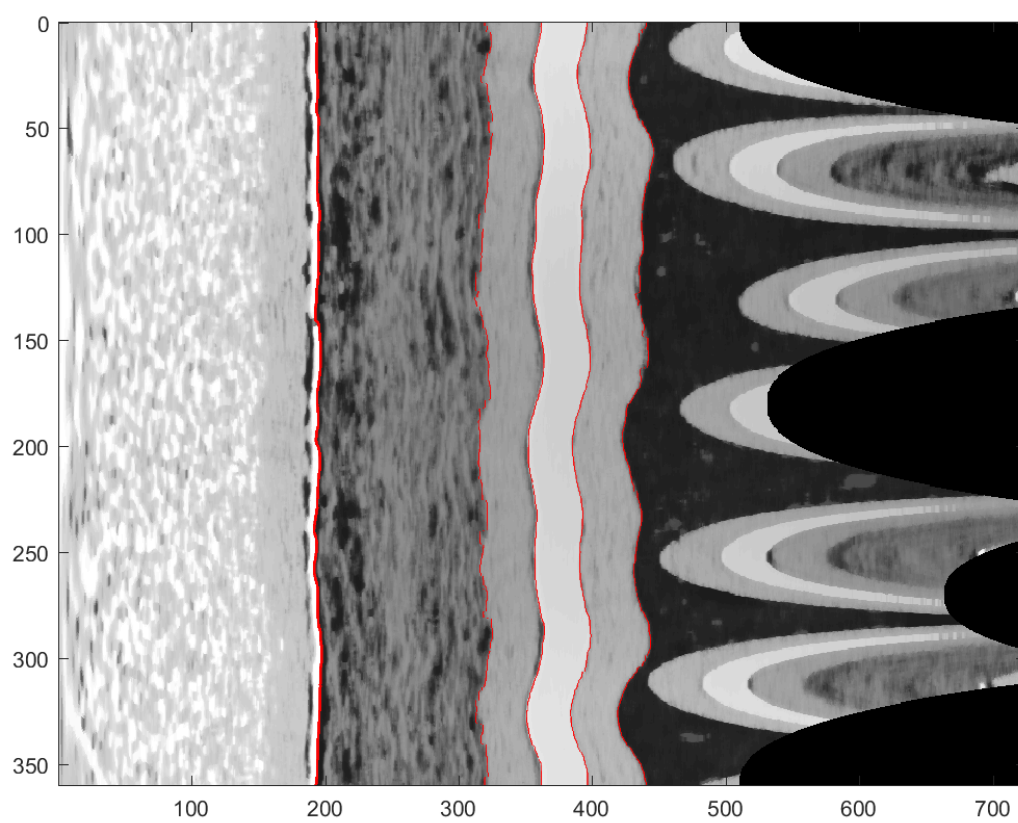


**P16082301N192 unwrapped**

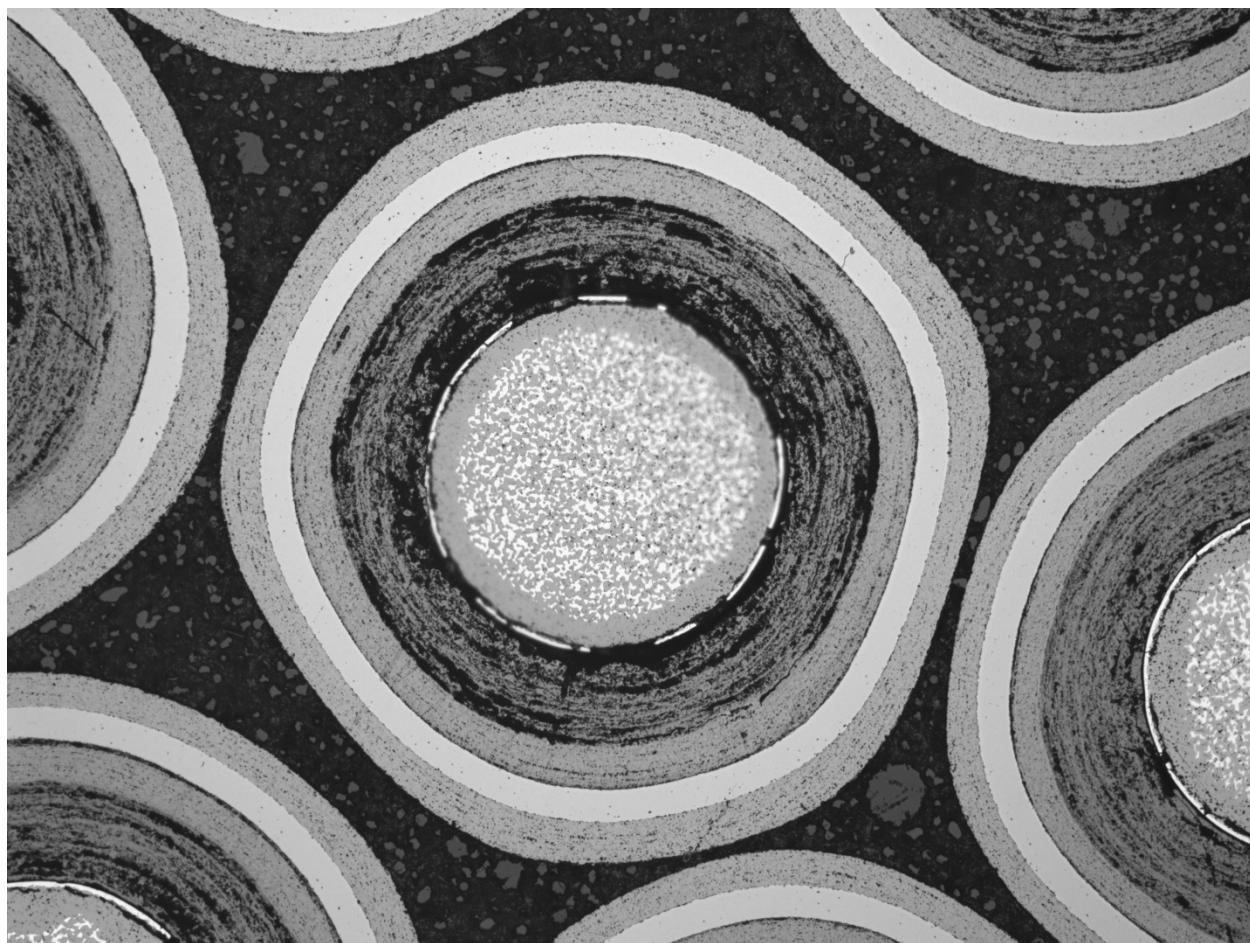




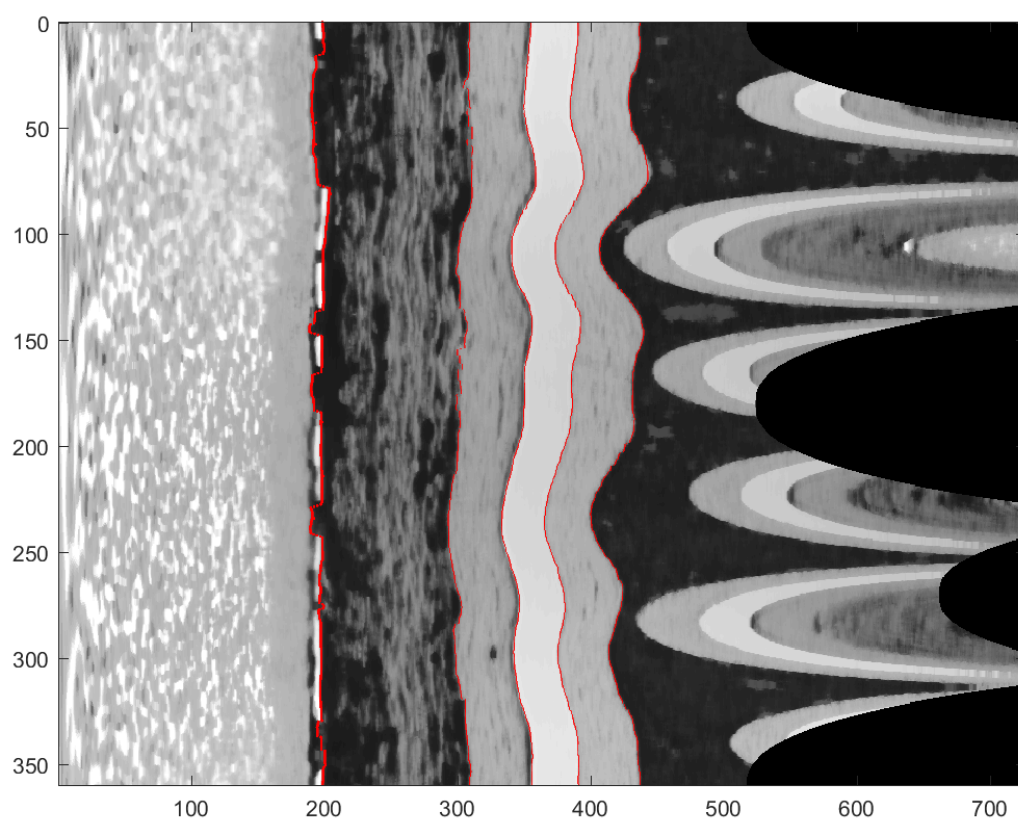
P16082301N193



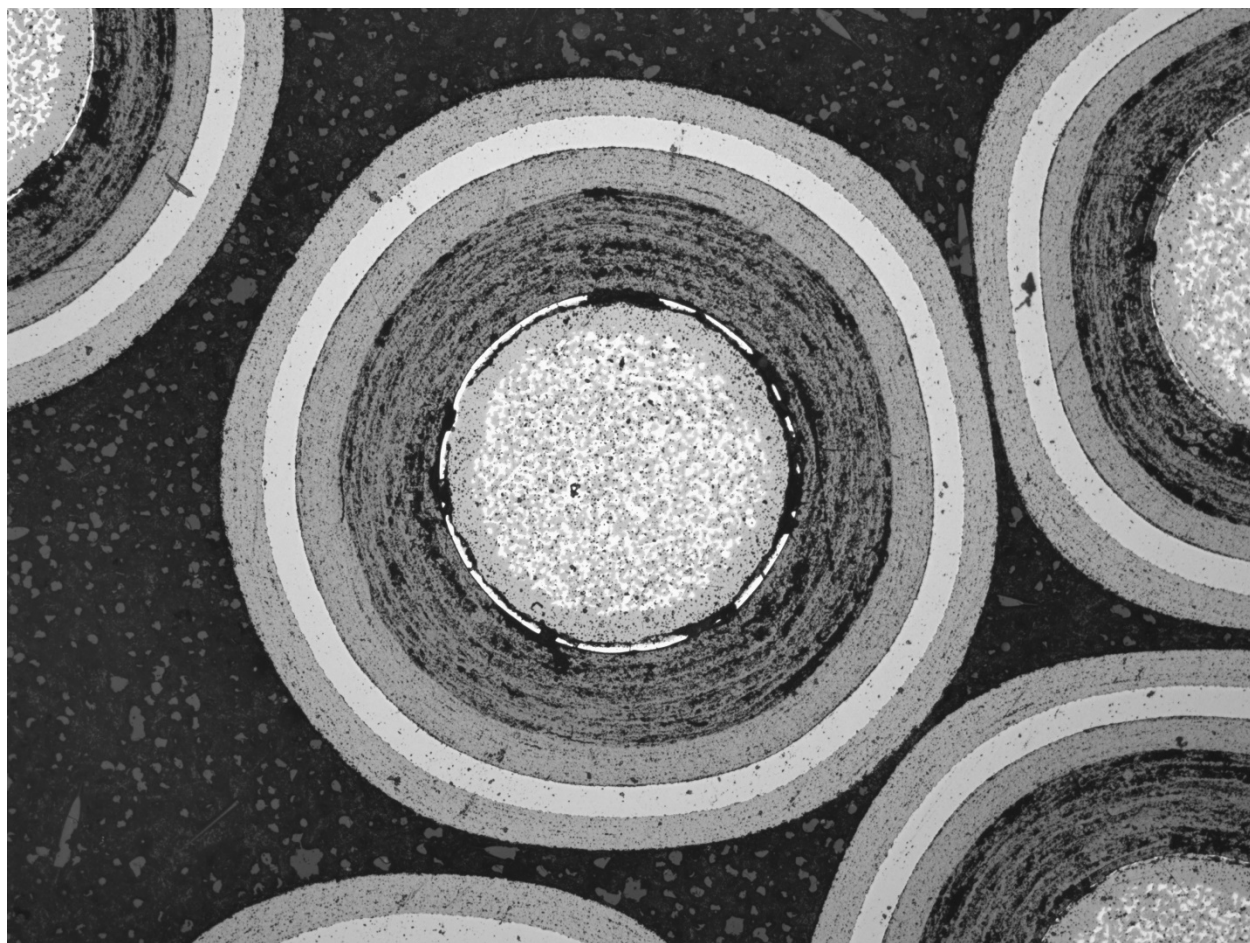
**P16082301N193 unwrapped**



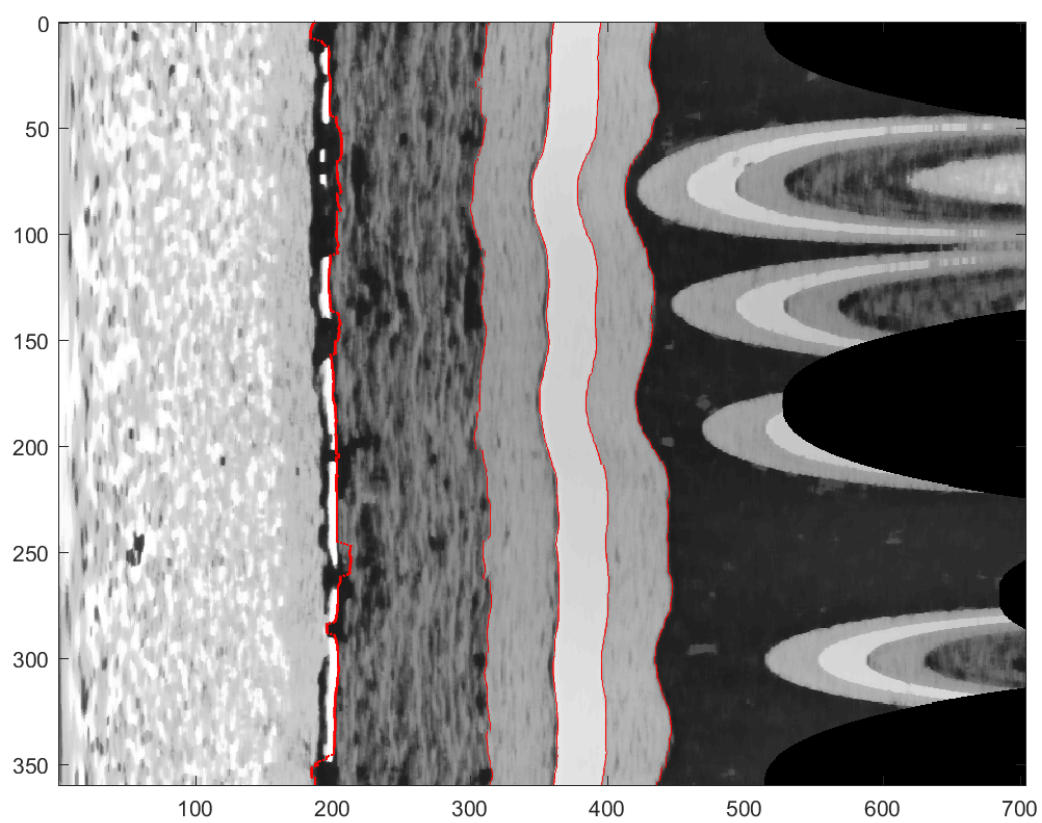
P16082301N194



**P16082301N194 unwrapped**

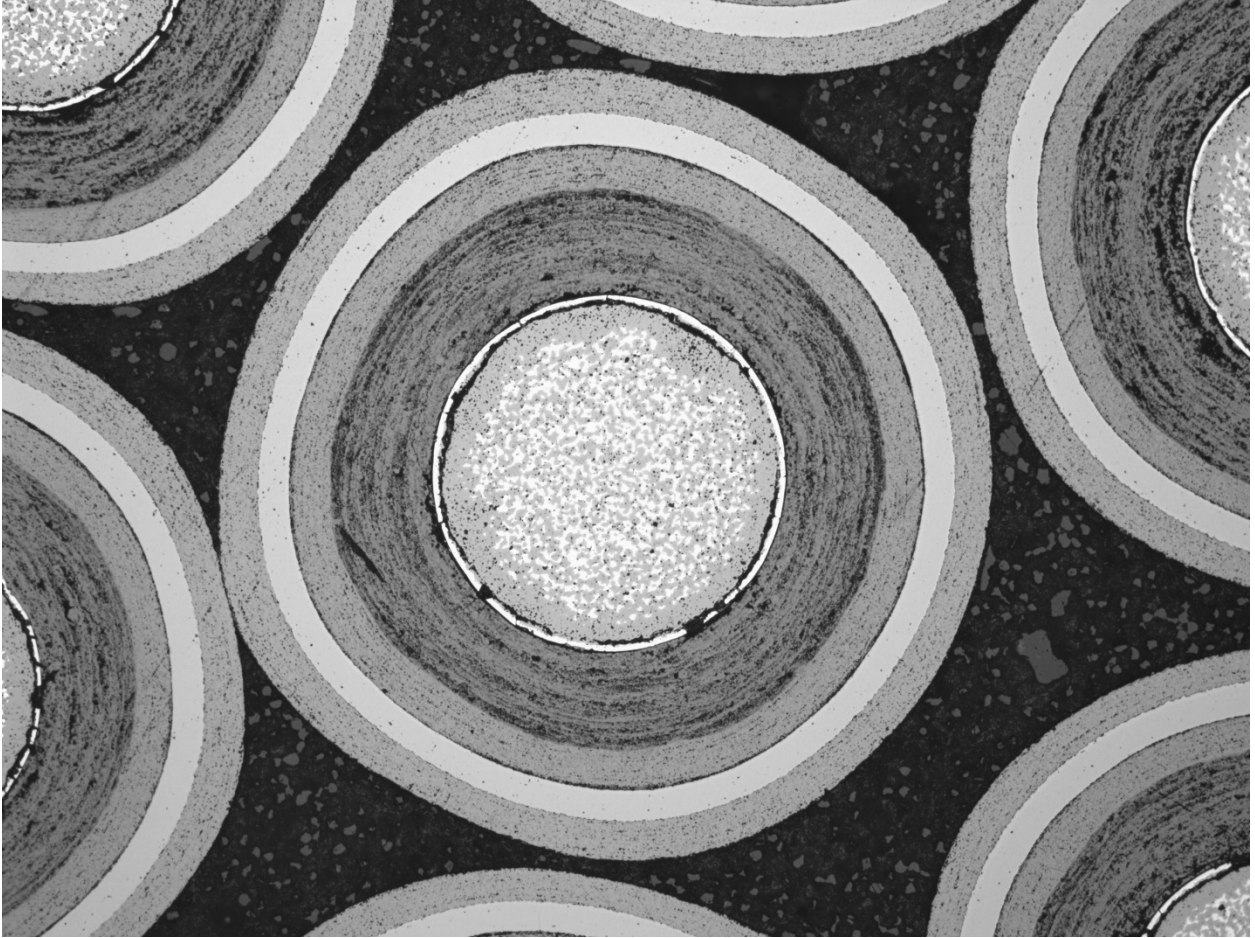


P16082301N195

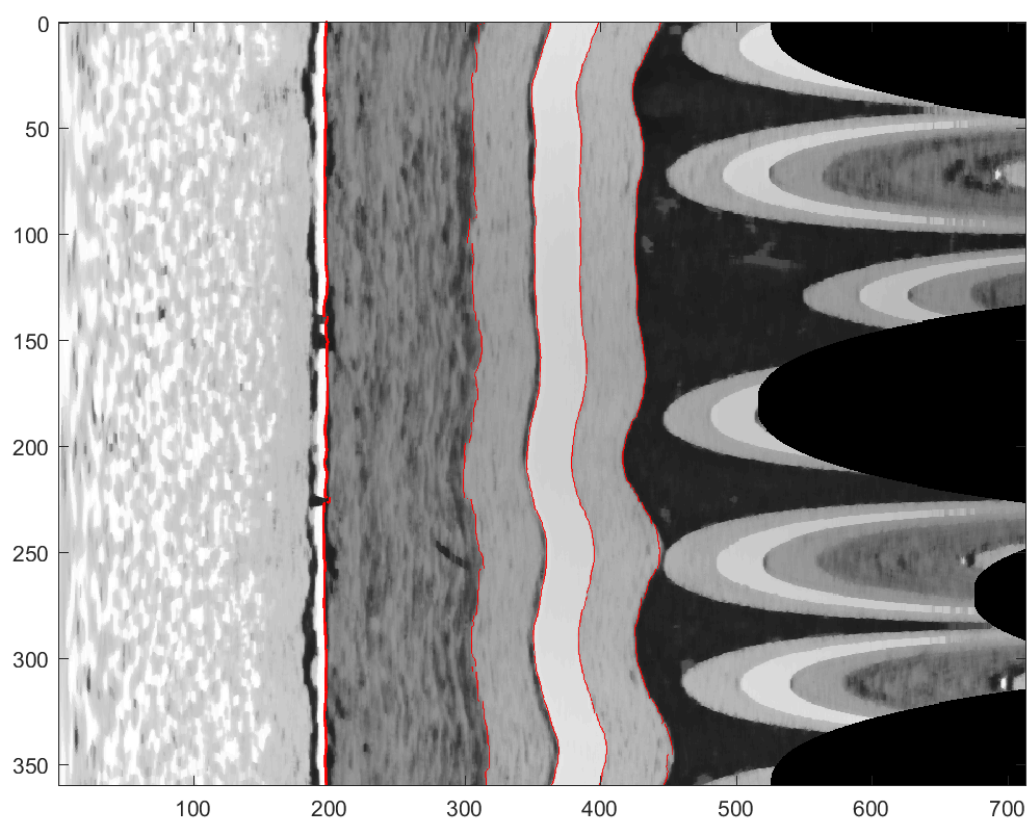


**P16082301N195 unwrapped**

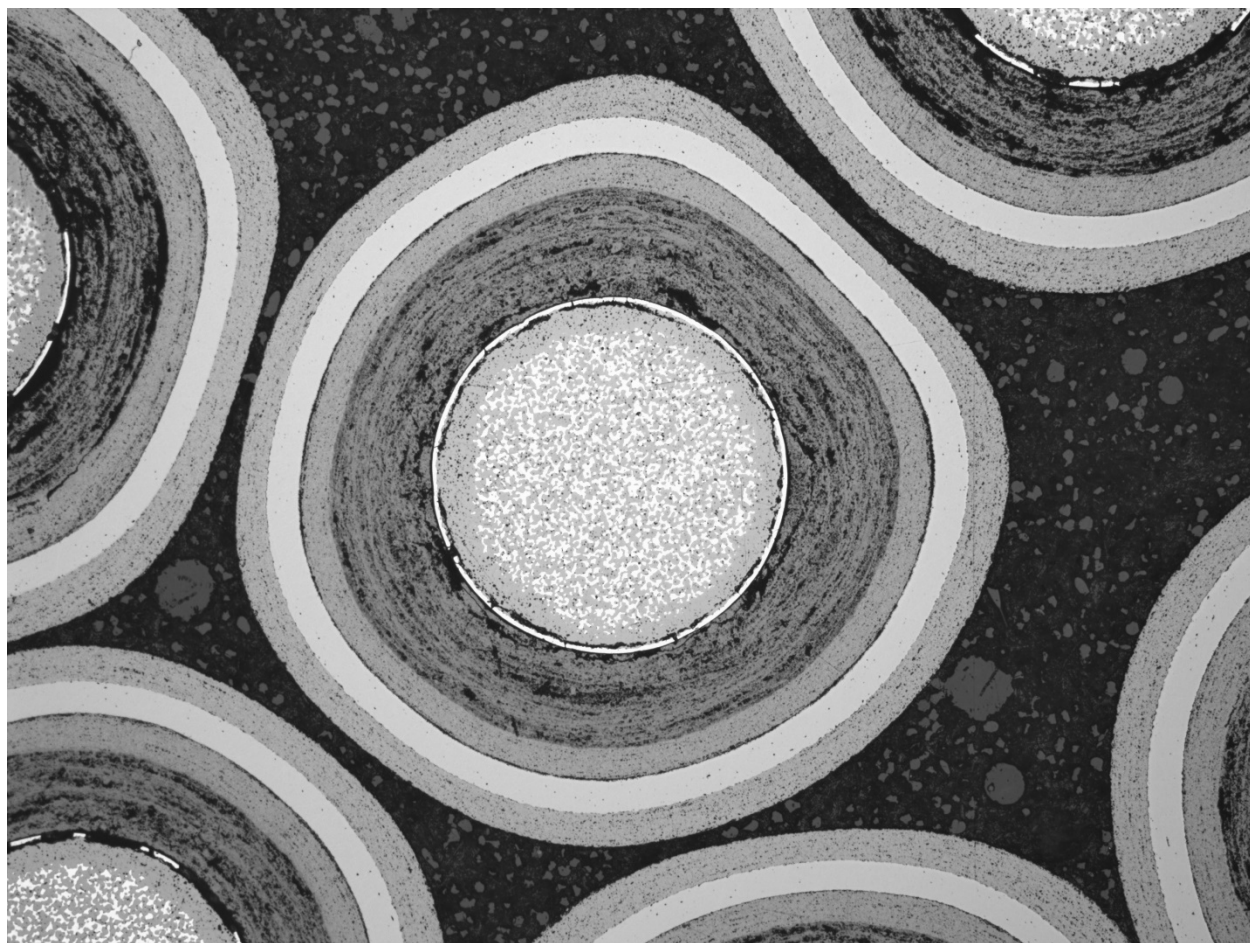




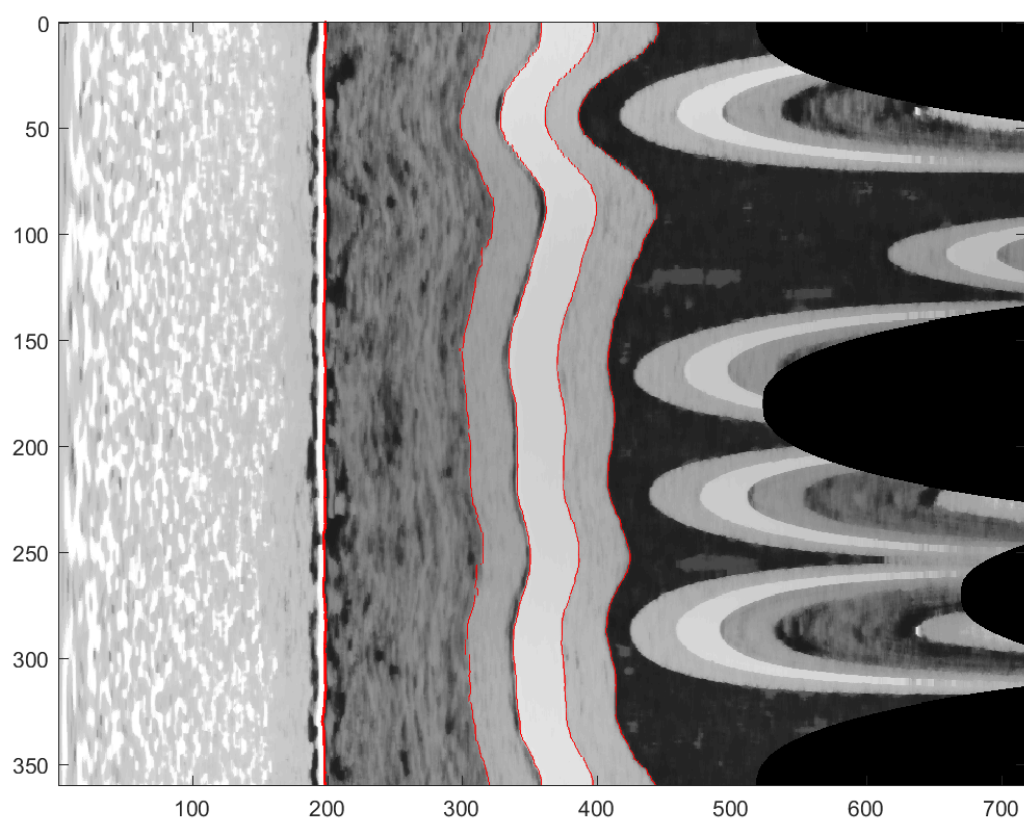
P16082301N196



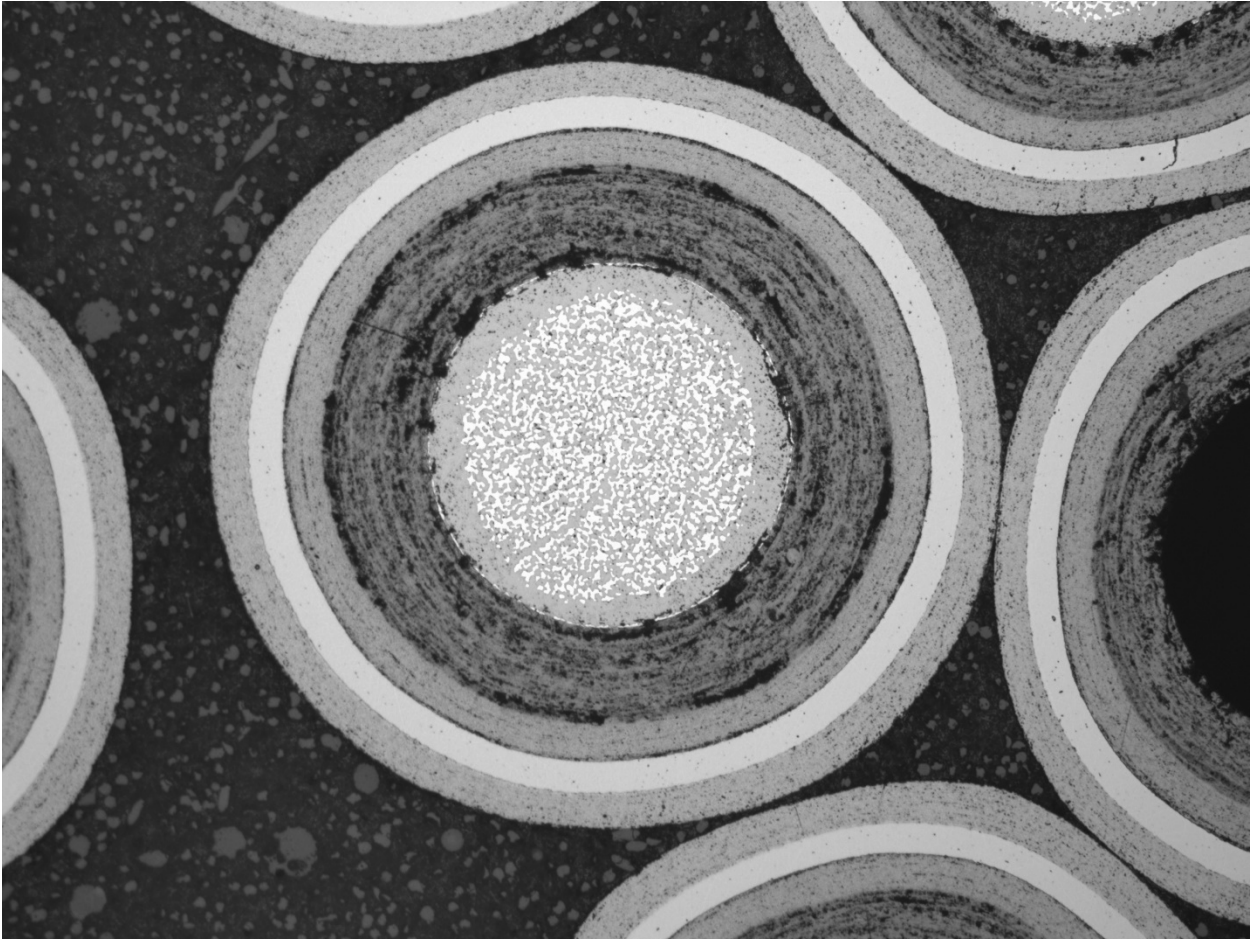
**P16082301N196 unwrapped**



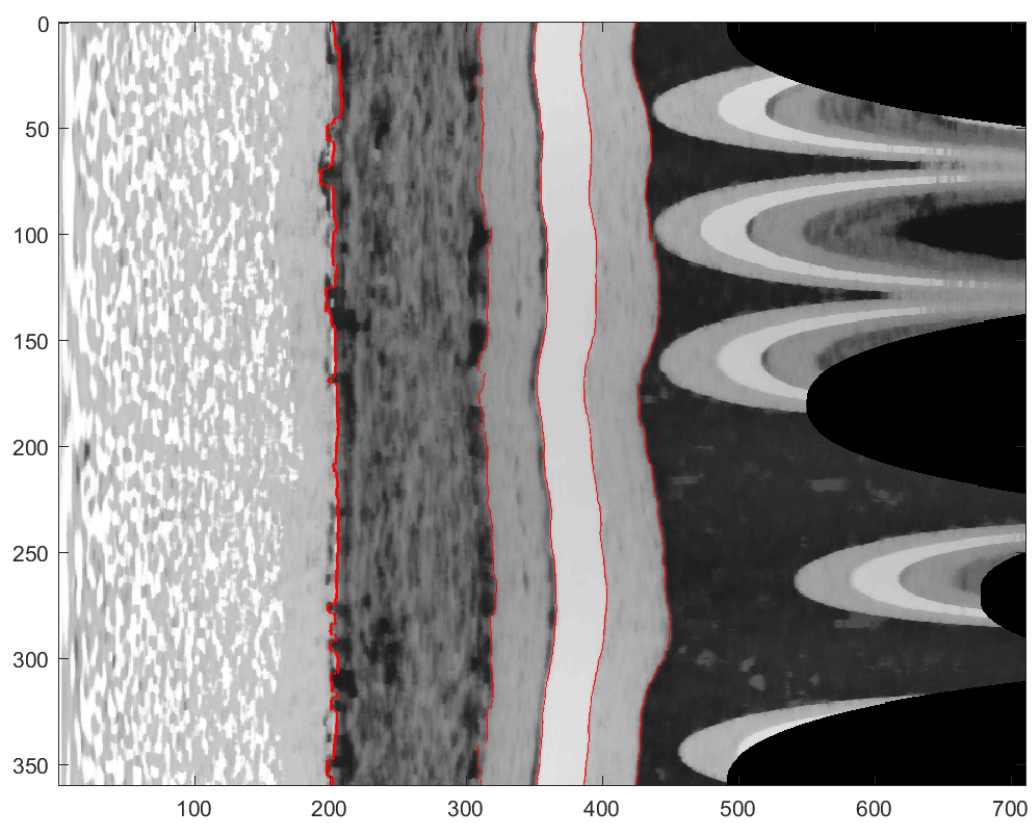
P16082301N197



**P16082301N197 unwrapped**

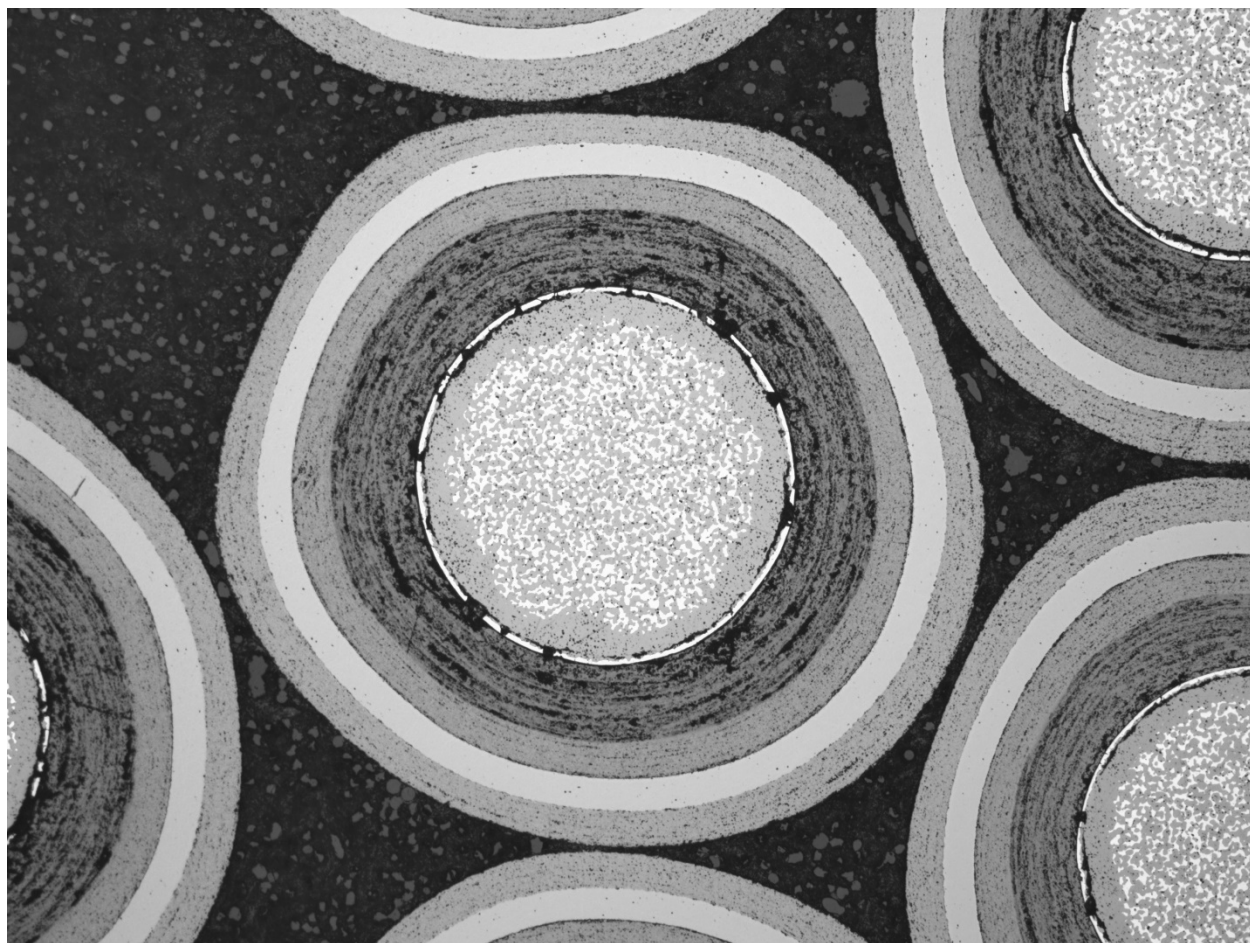


P16082301N198

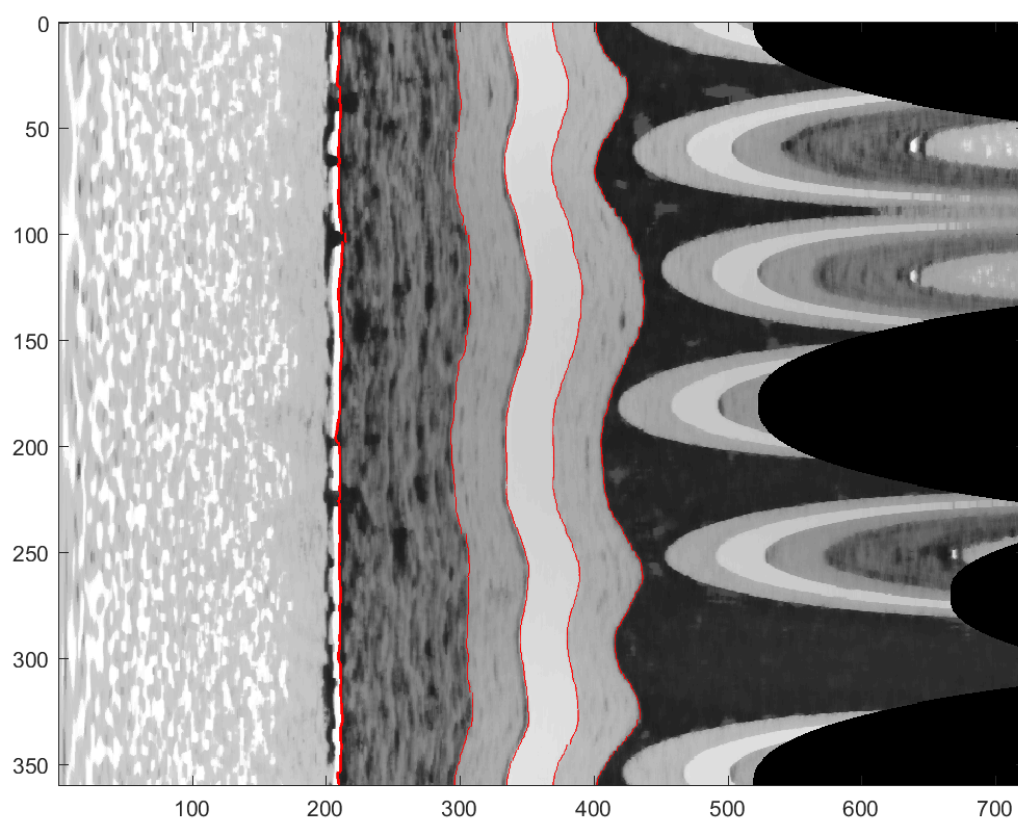


**P16082301N198 unwrapped**

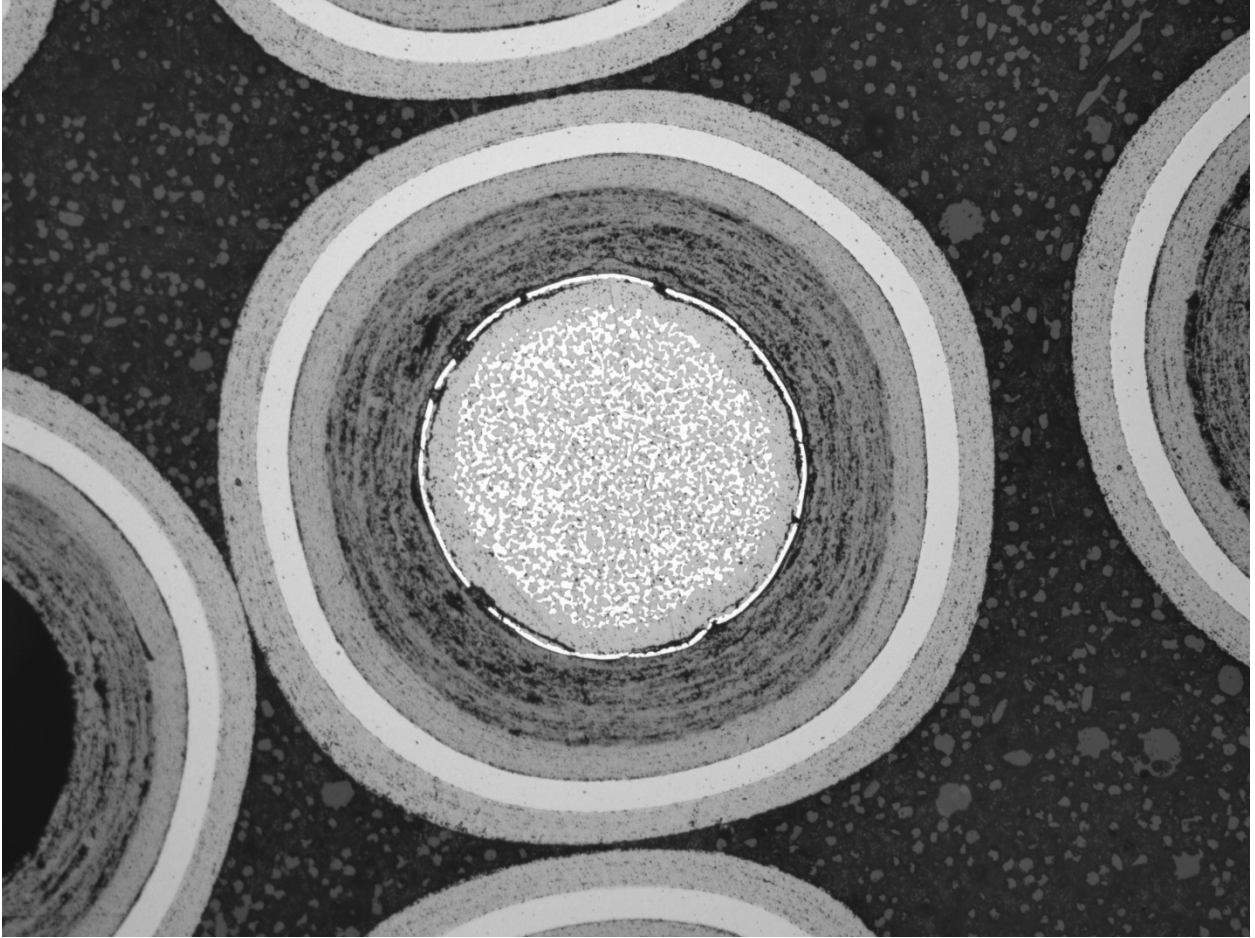




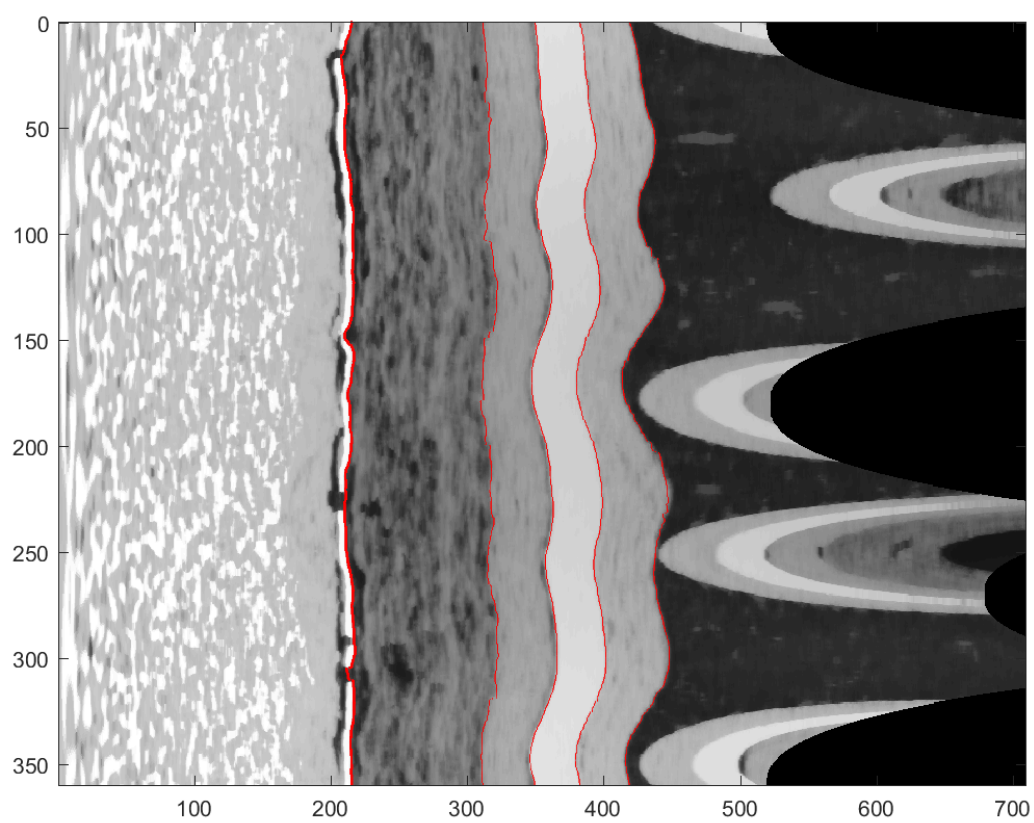
P16082301N199



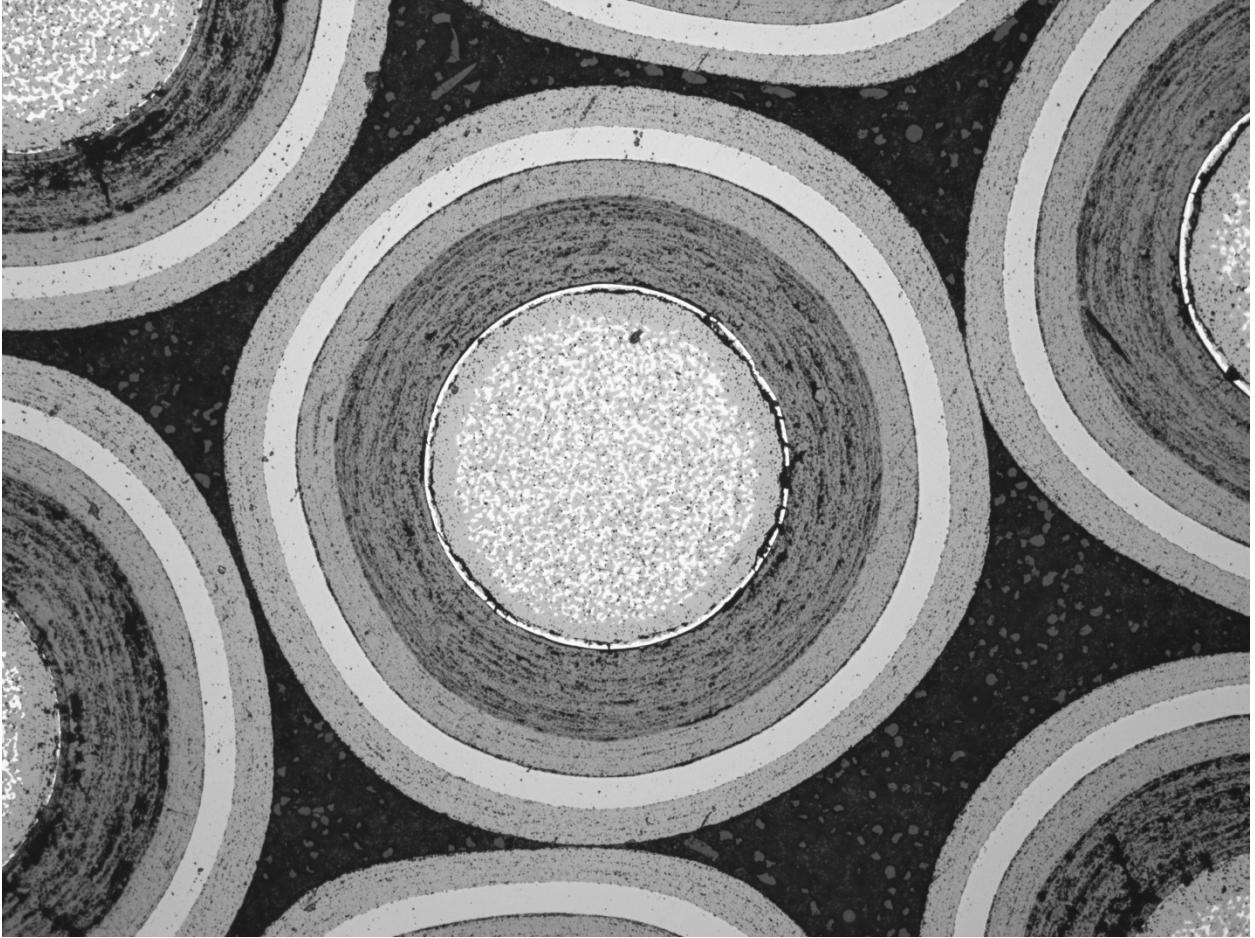
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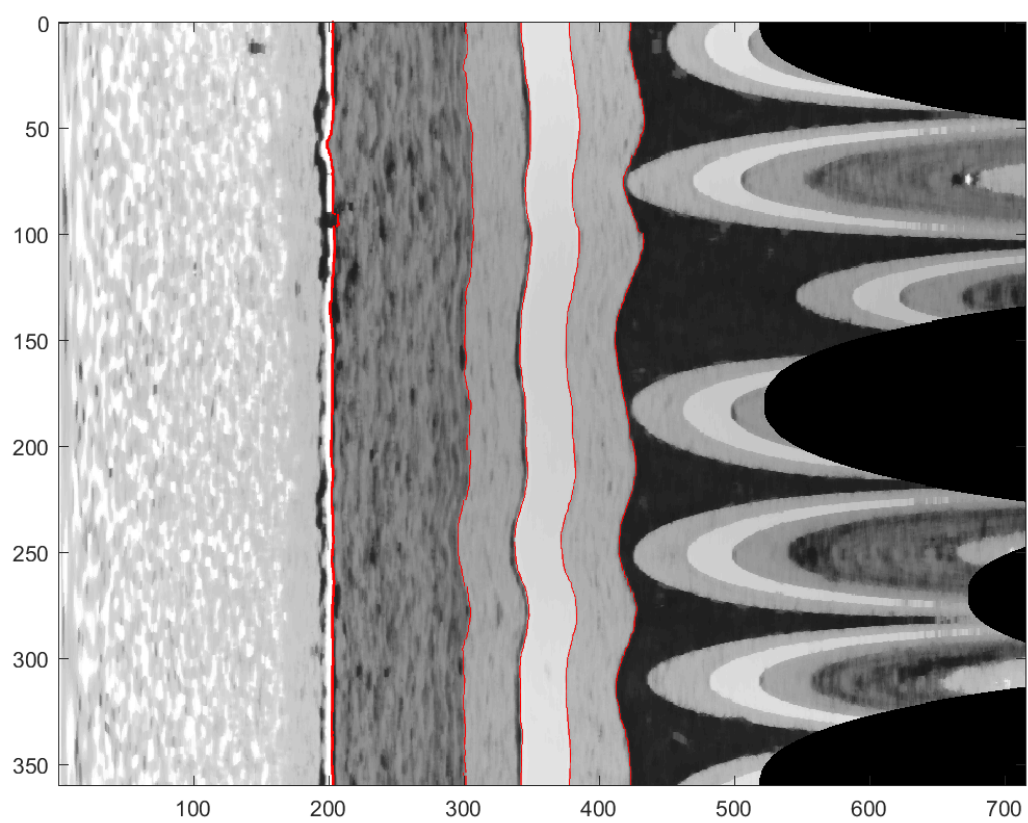
P16082301N200



**P16082301N200 unwrapped**

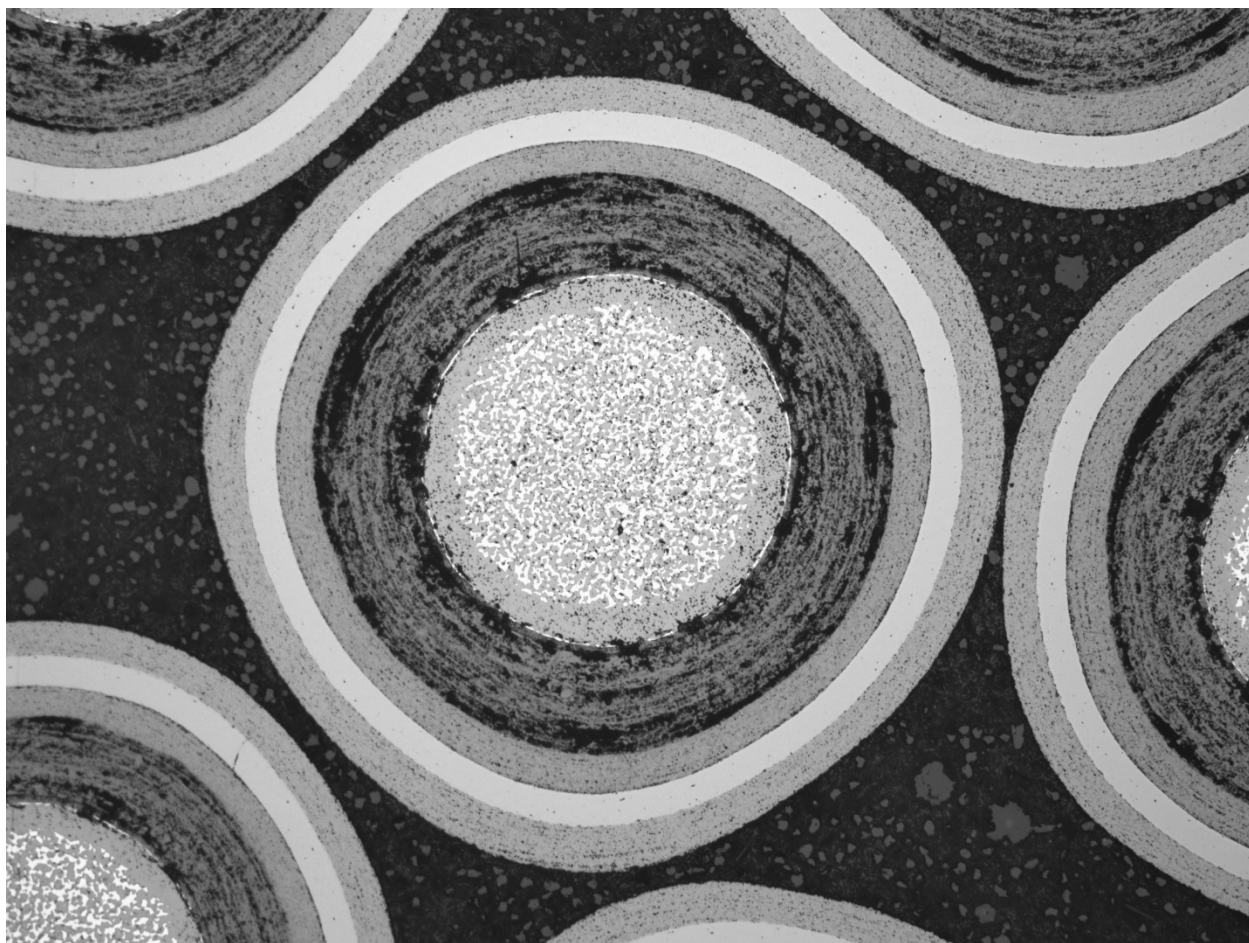


P16082301N202

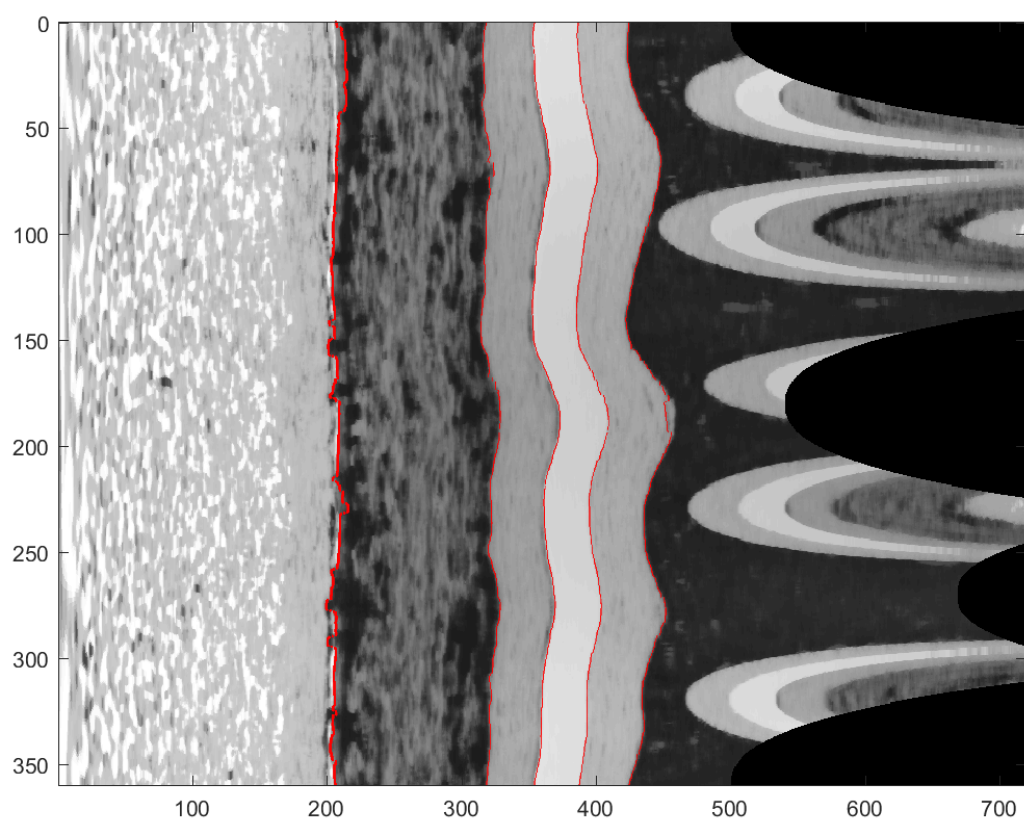


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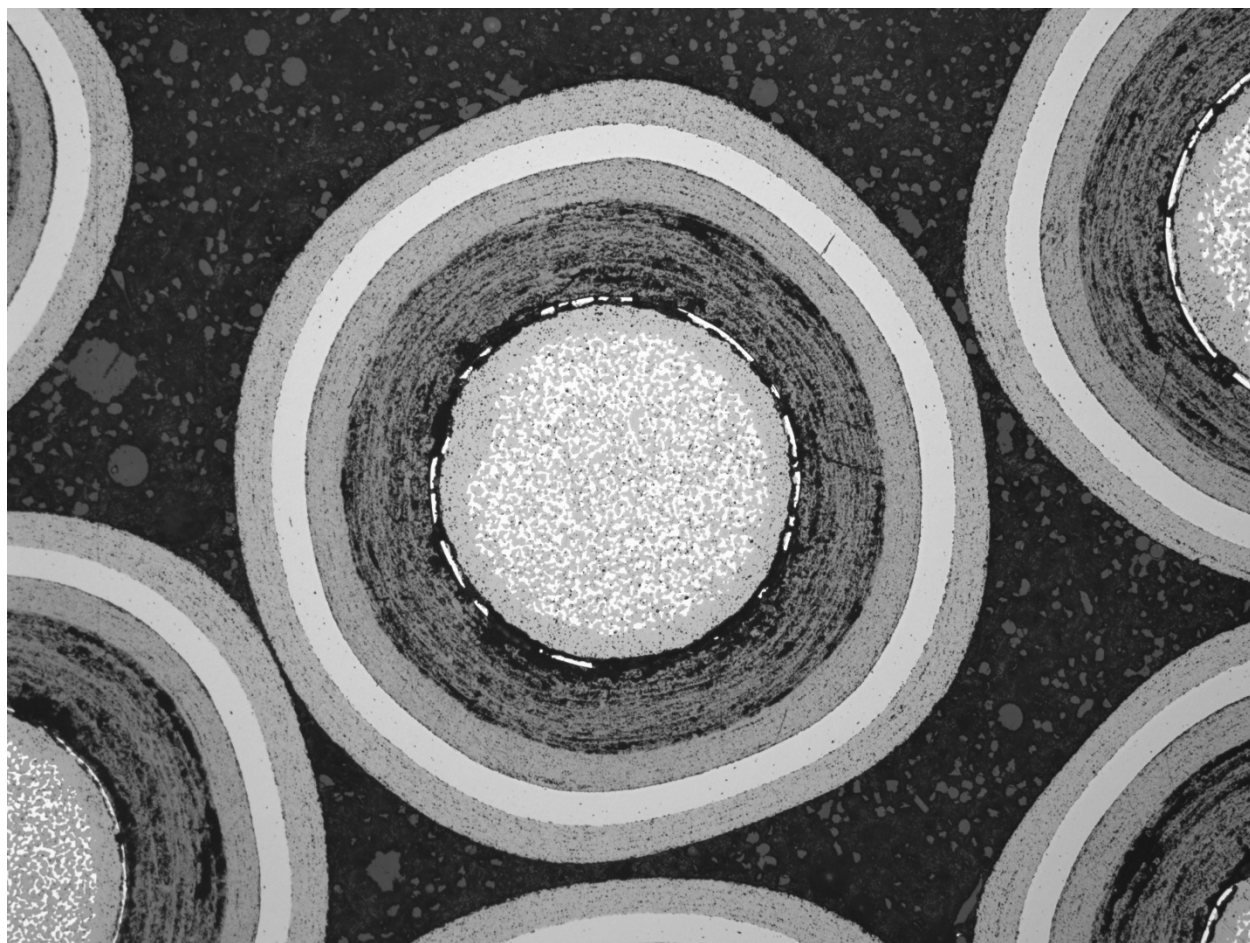




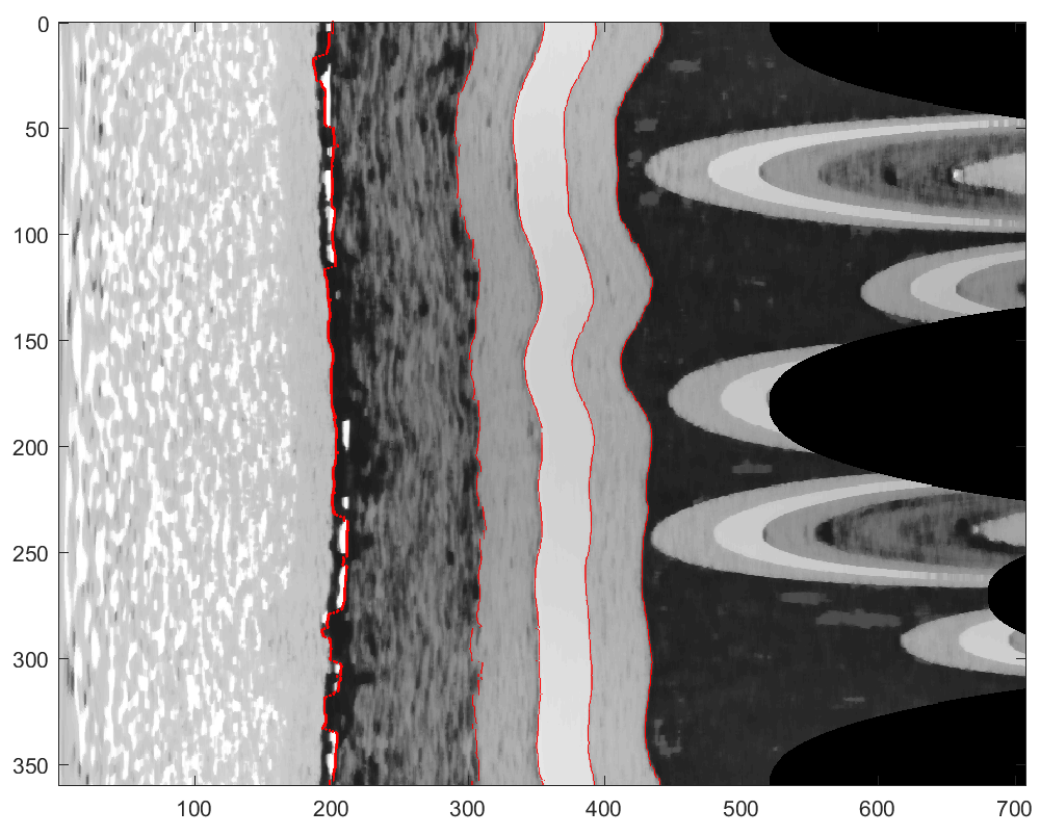
P16082301N204



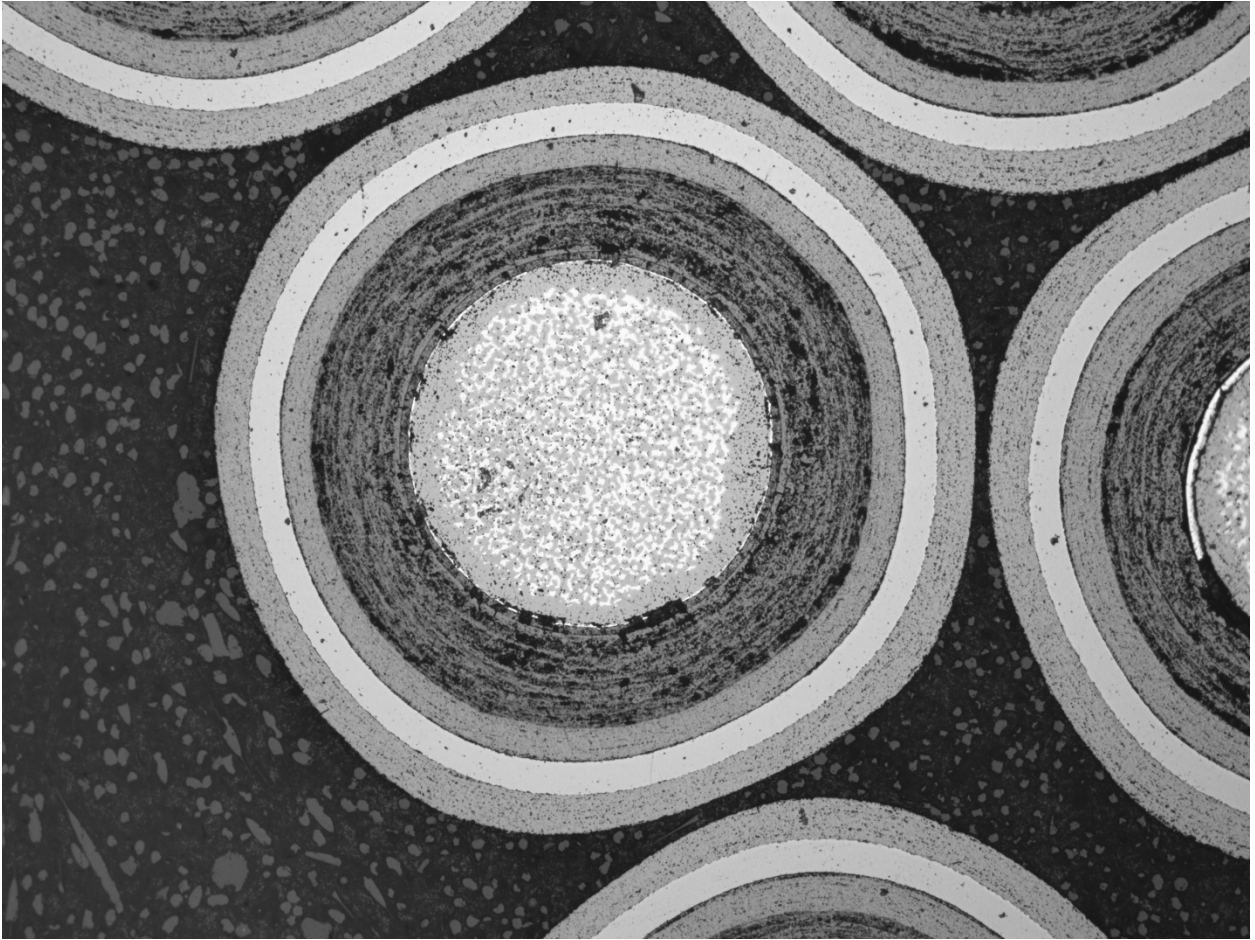
**P16082301N204 unwrapped**



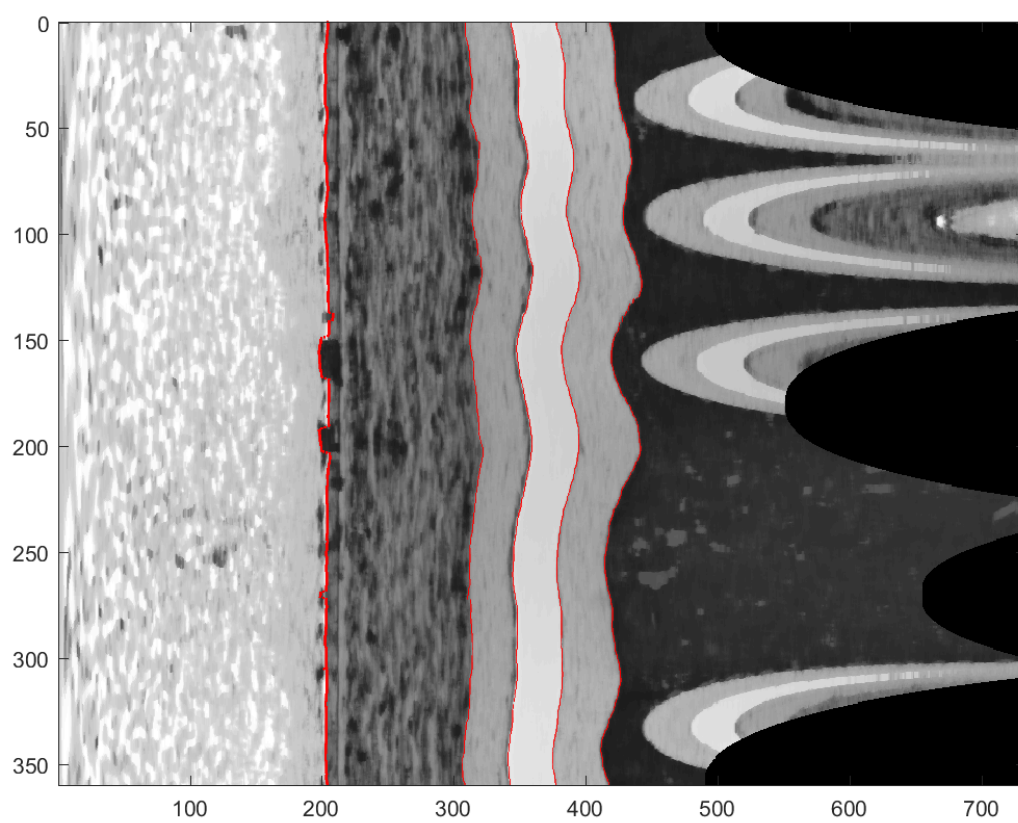
P16082301N205



**P16082301N205 unwrapped**

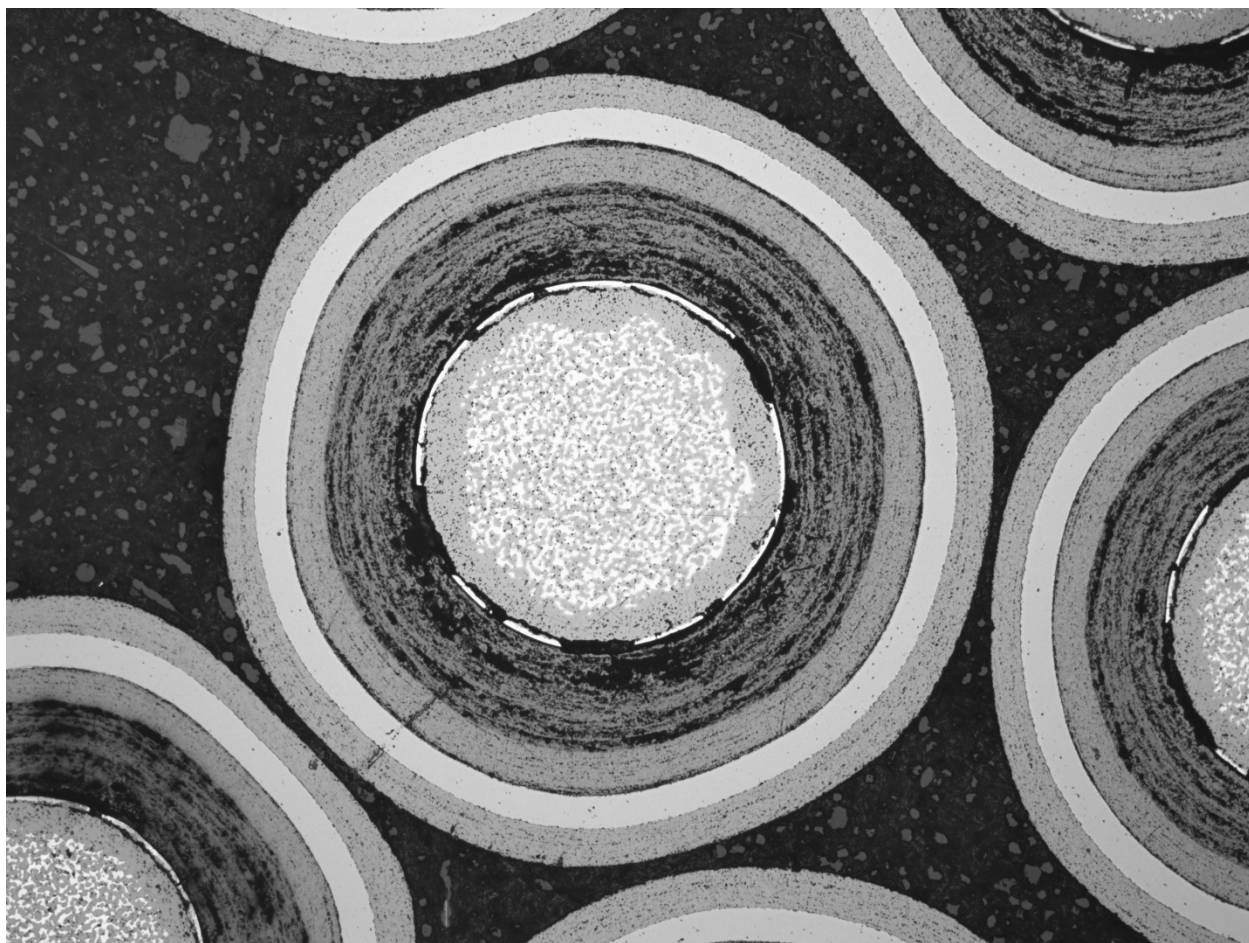


P16082301N206

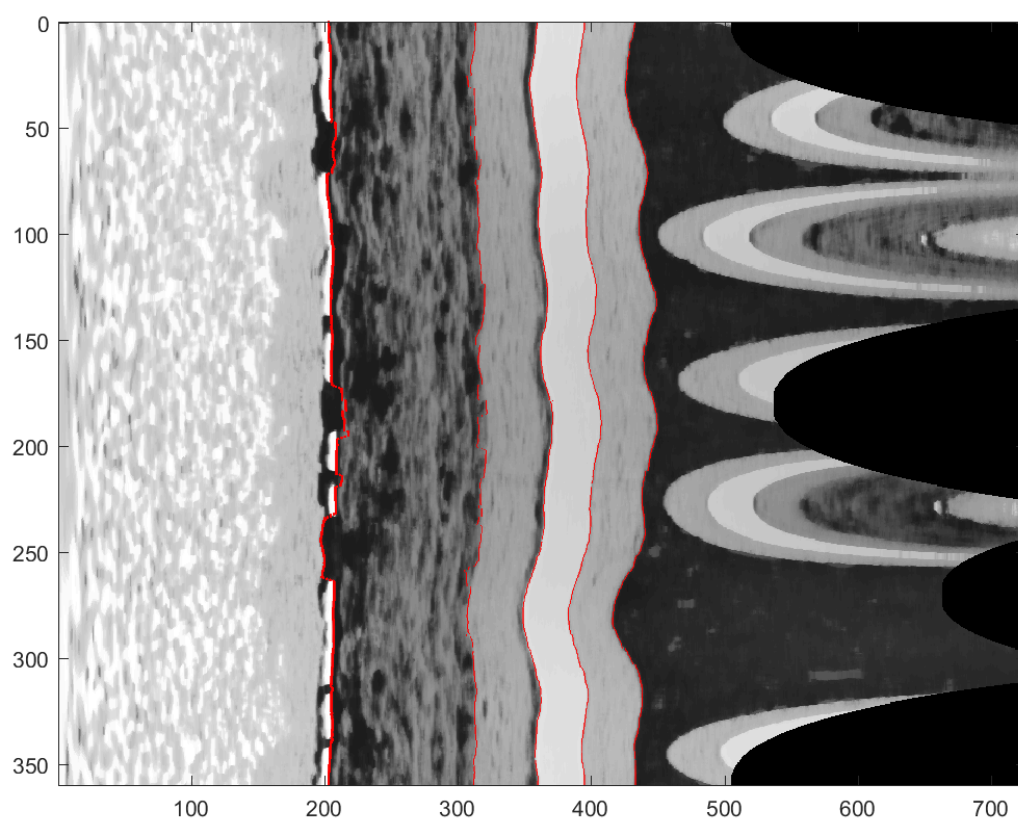


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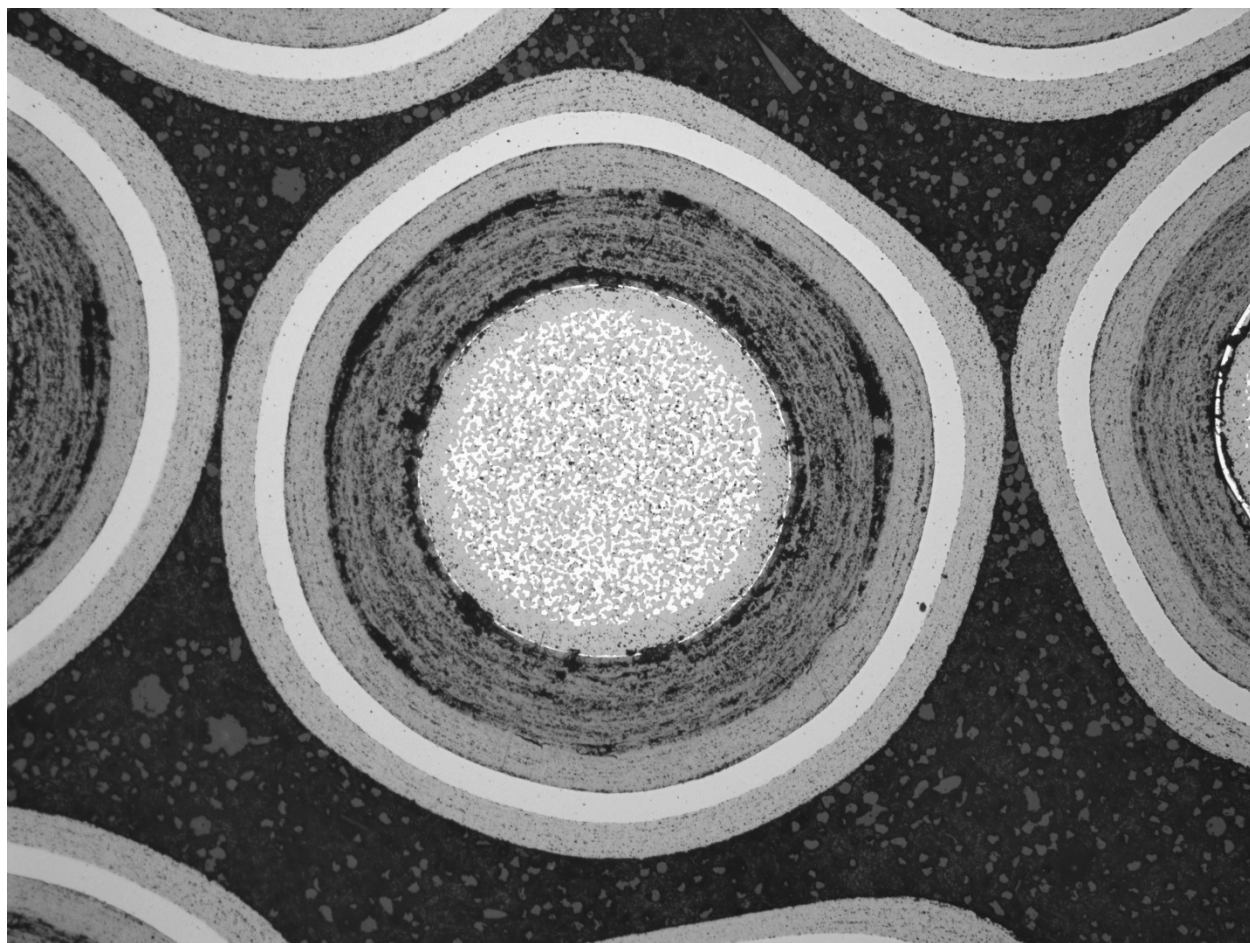




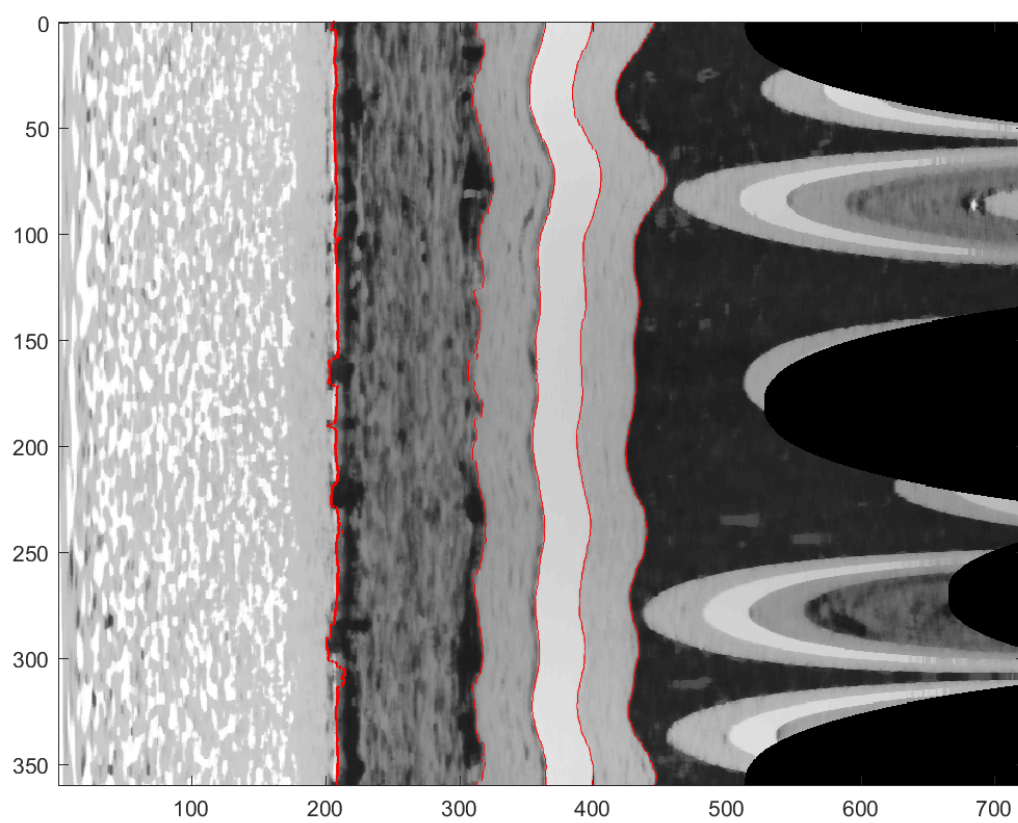
P16082301N209



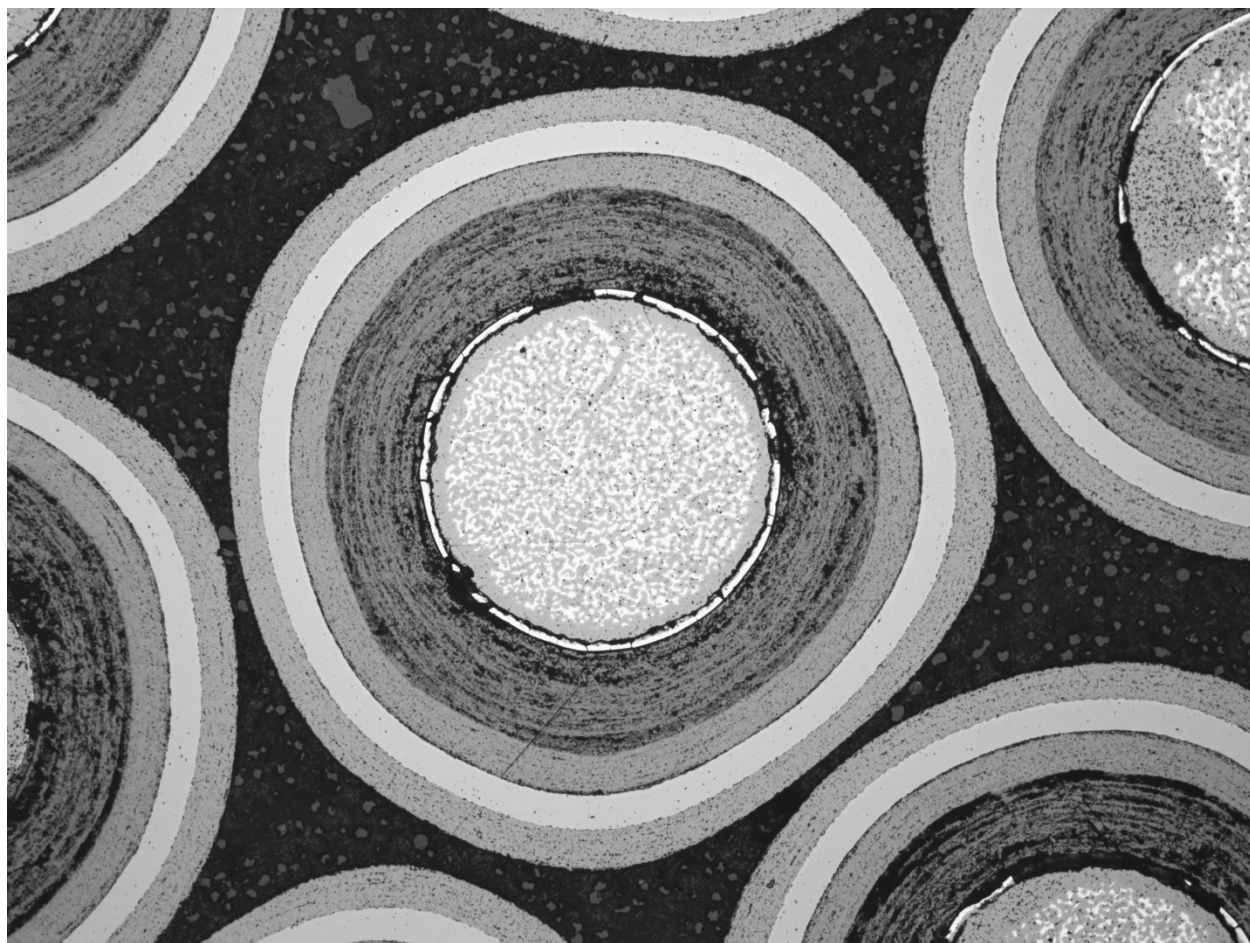
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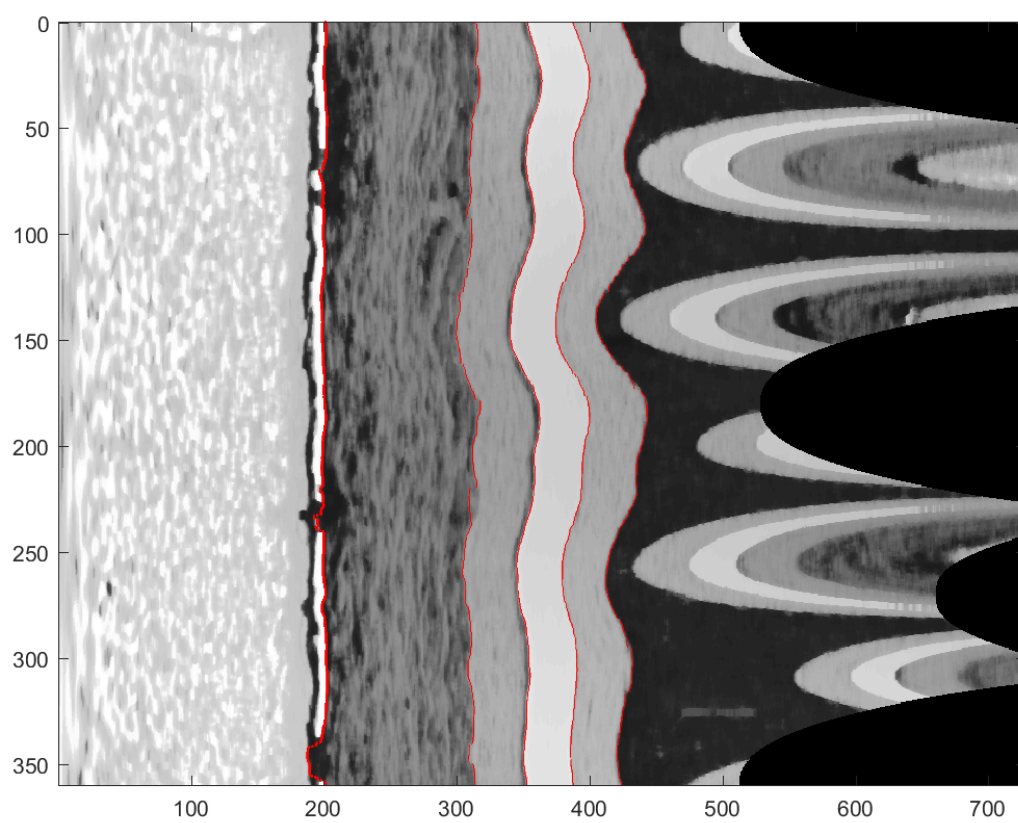
P16082301N211



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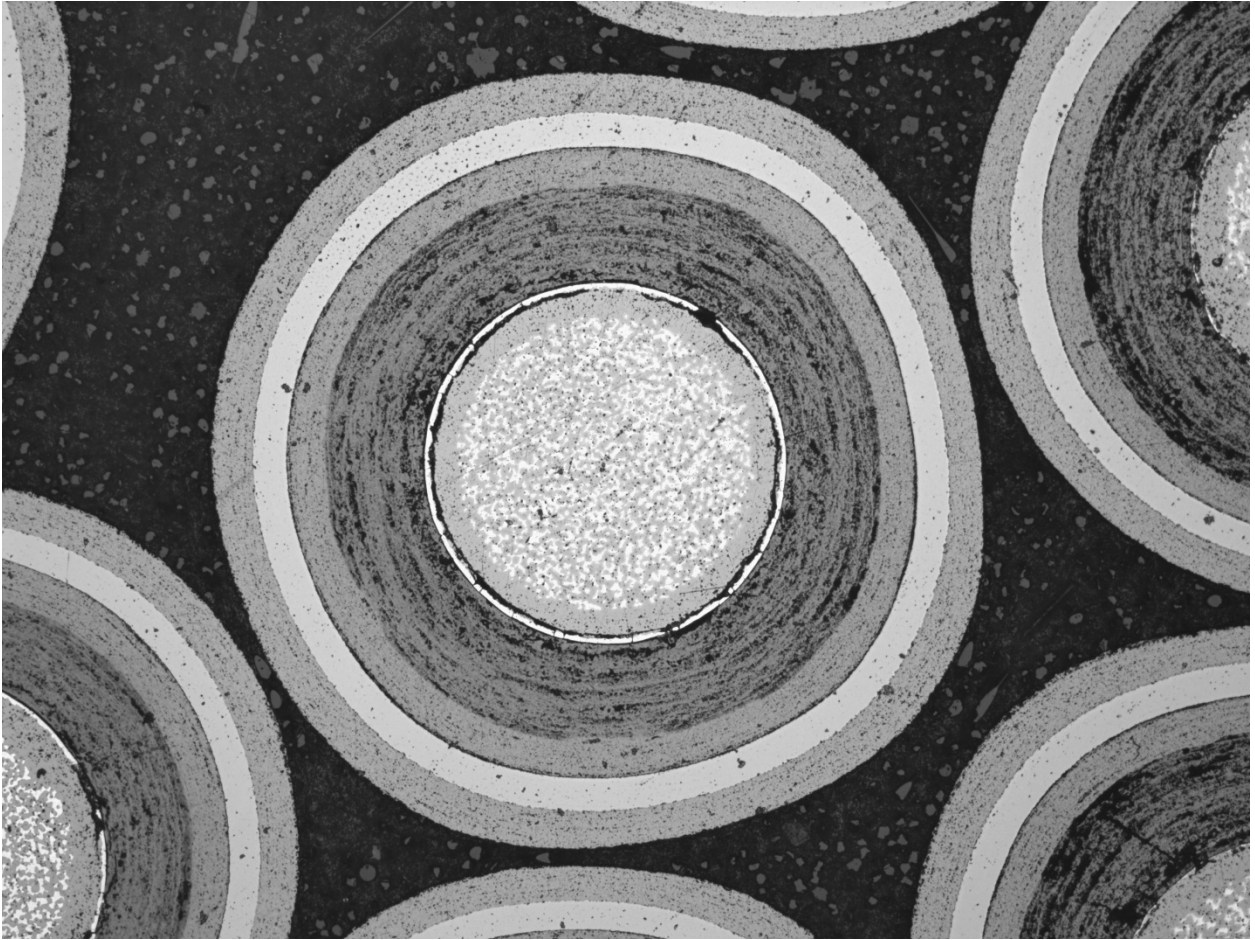


P16082301N214

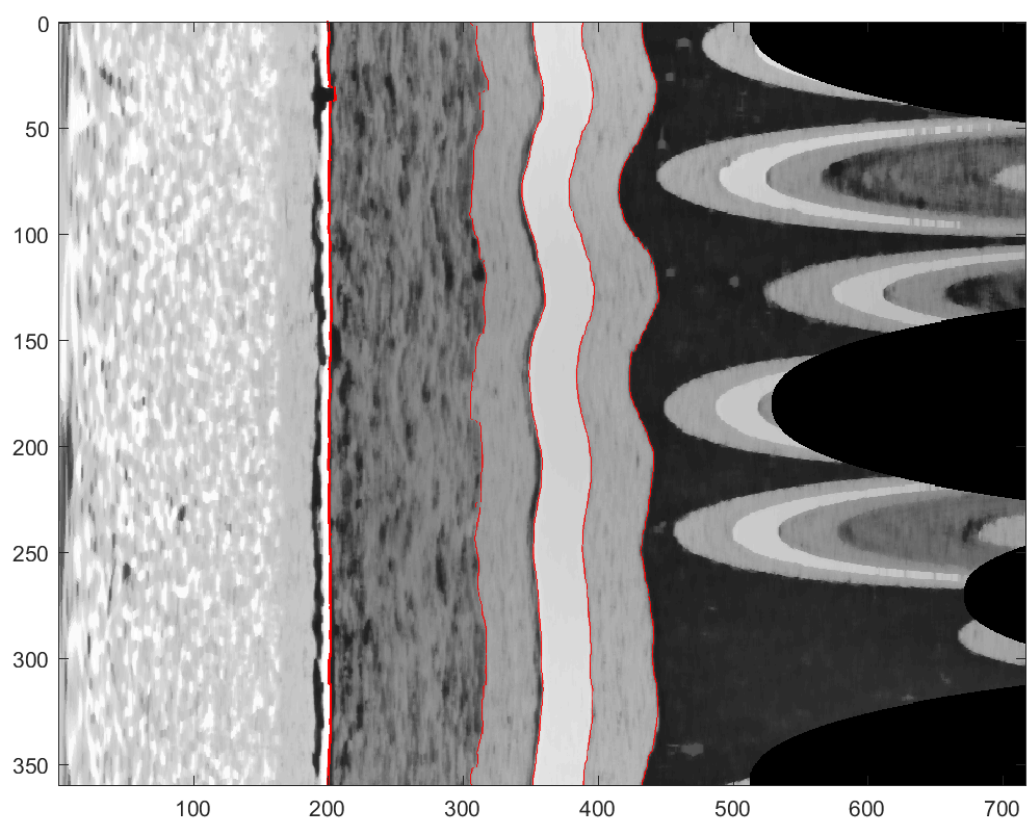


**P16082301N214 unwrapped**

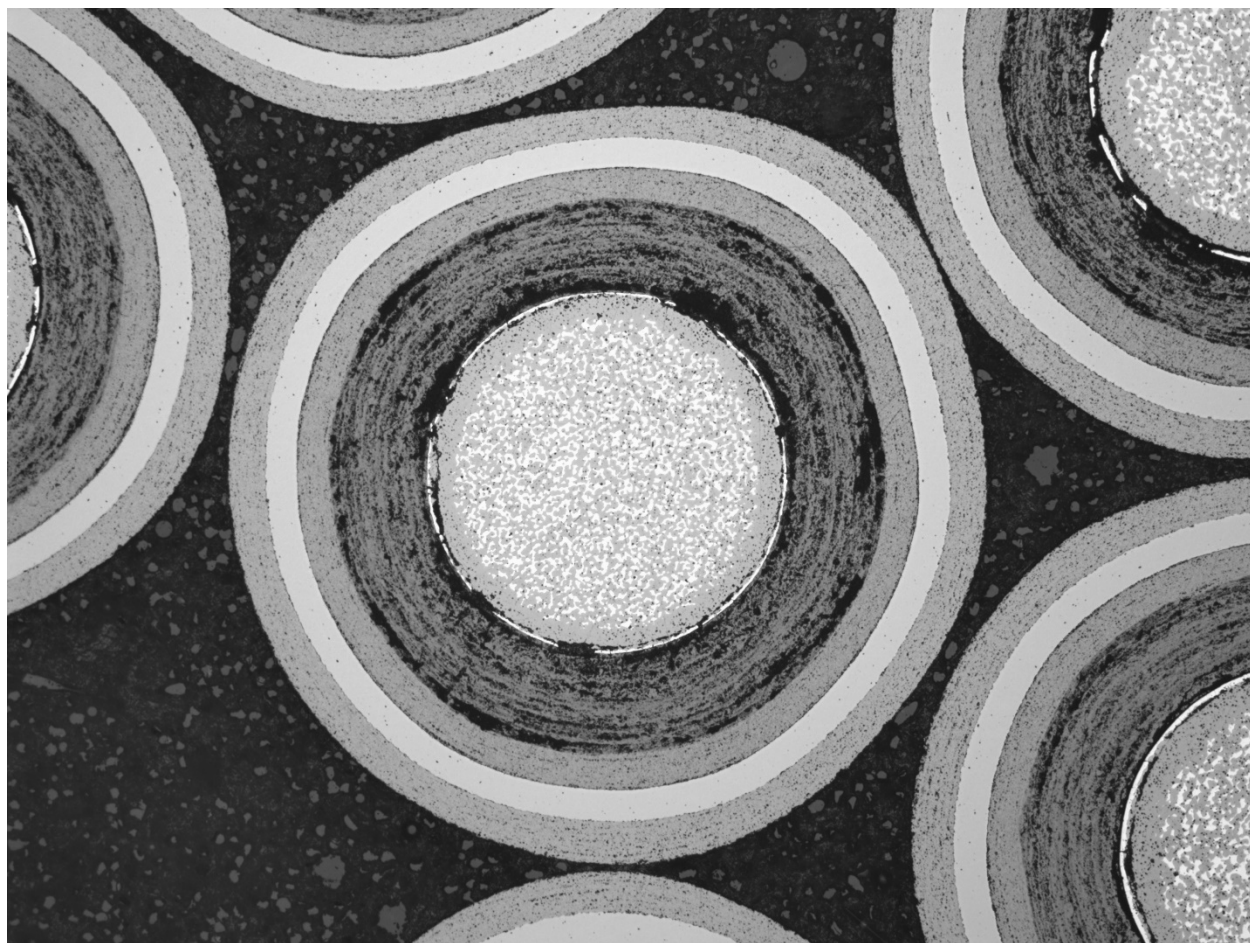




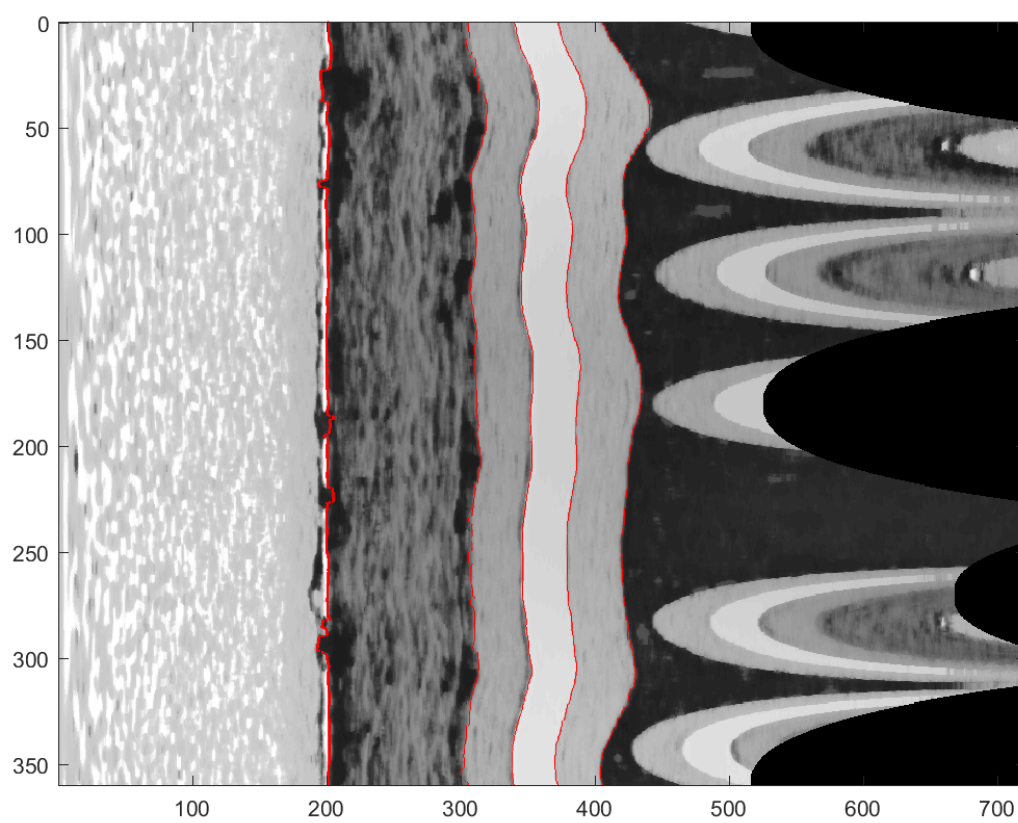
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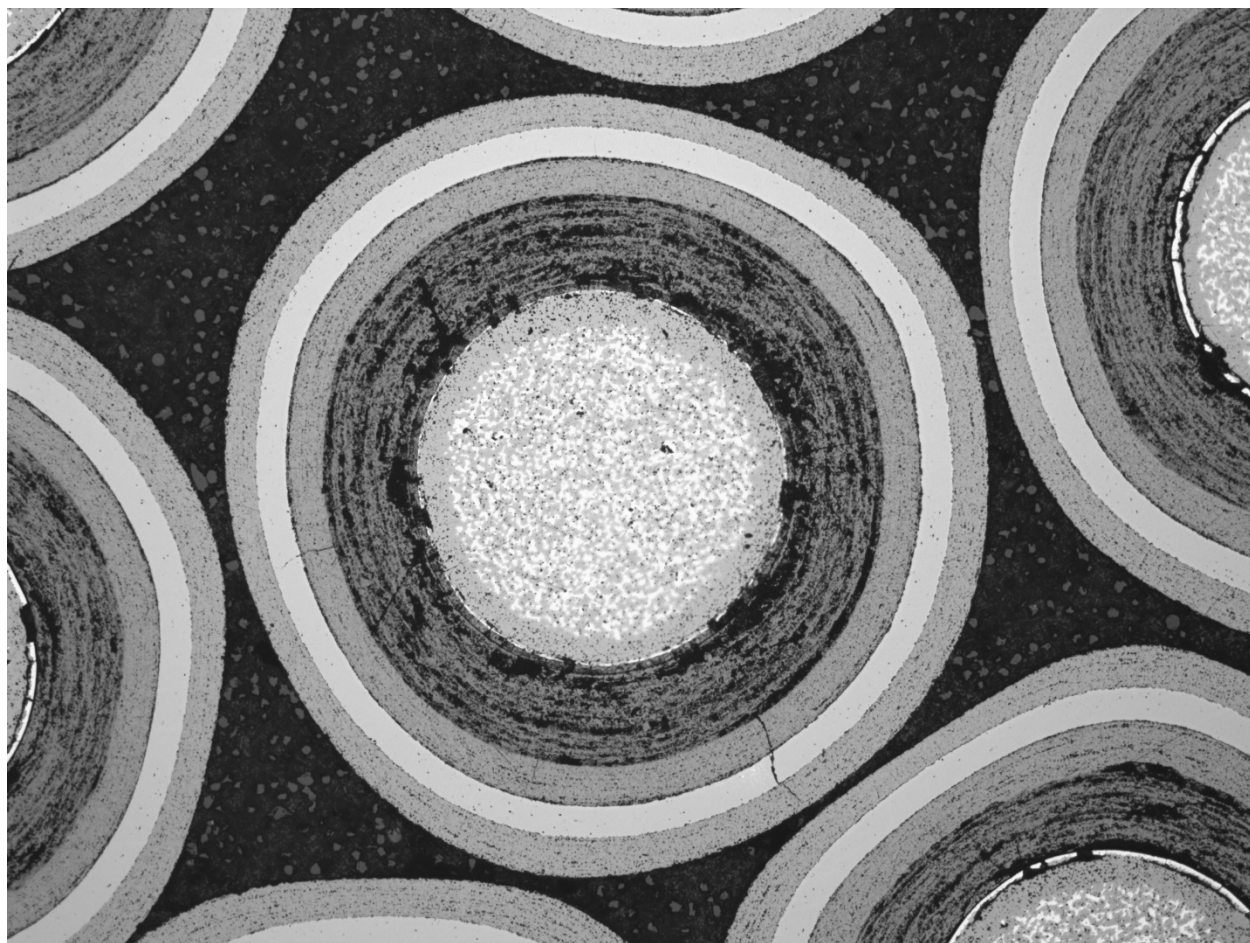
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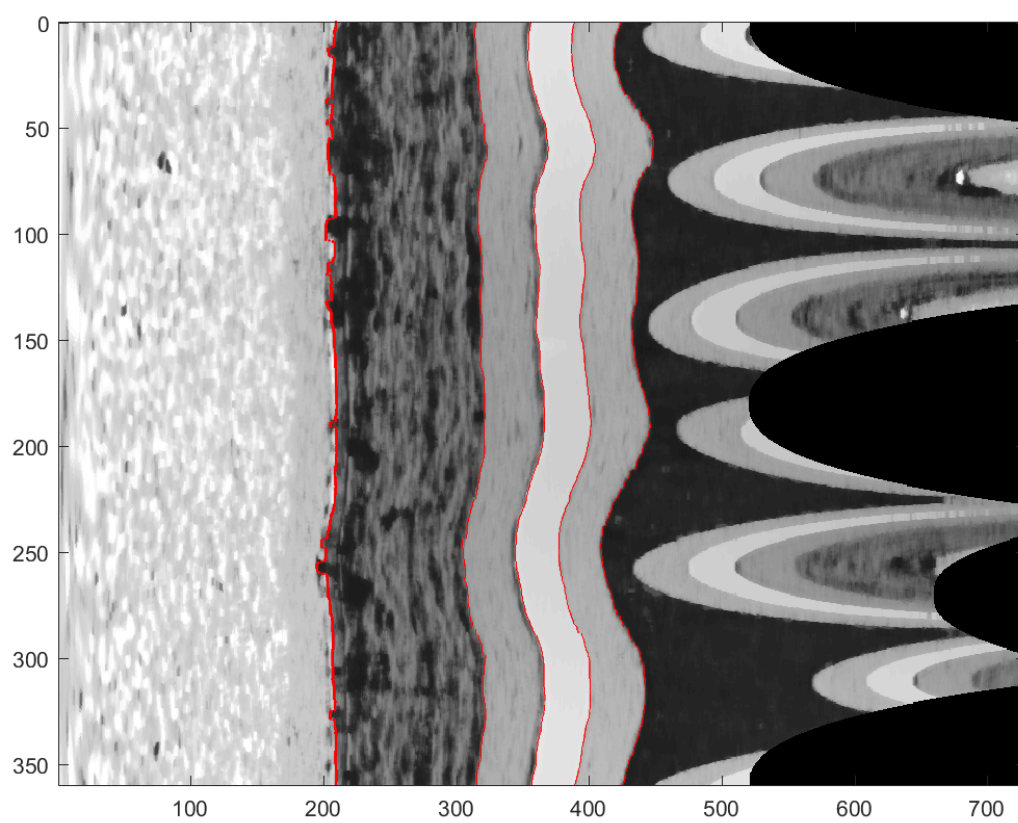
P16082301N218



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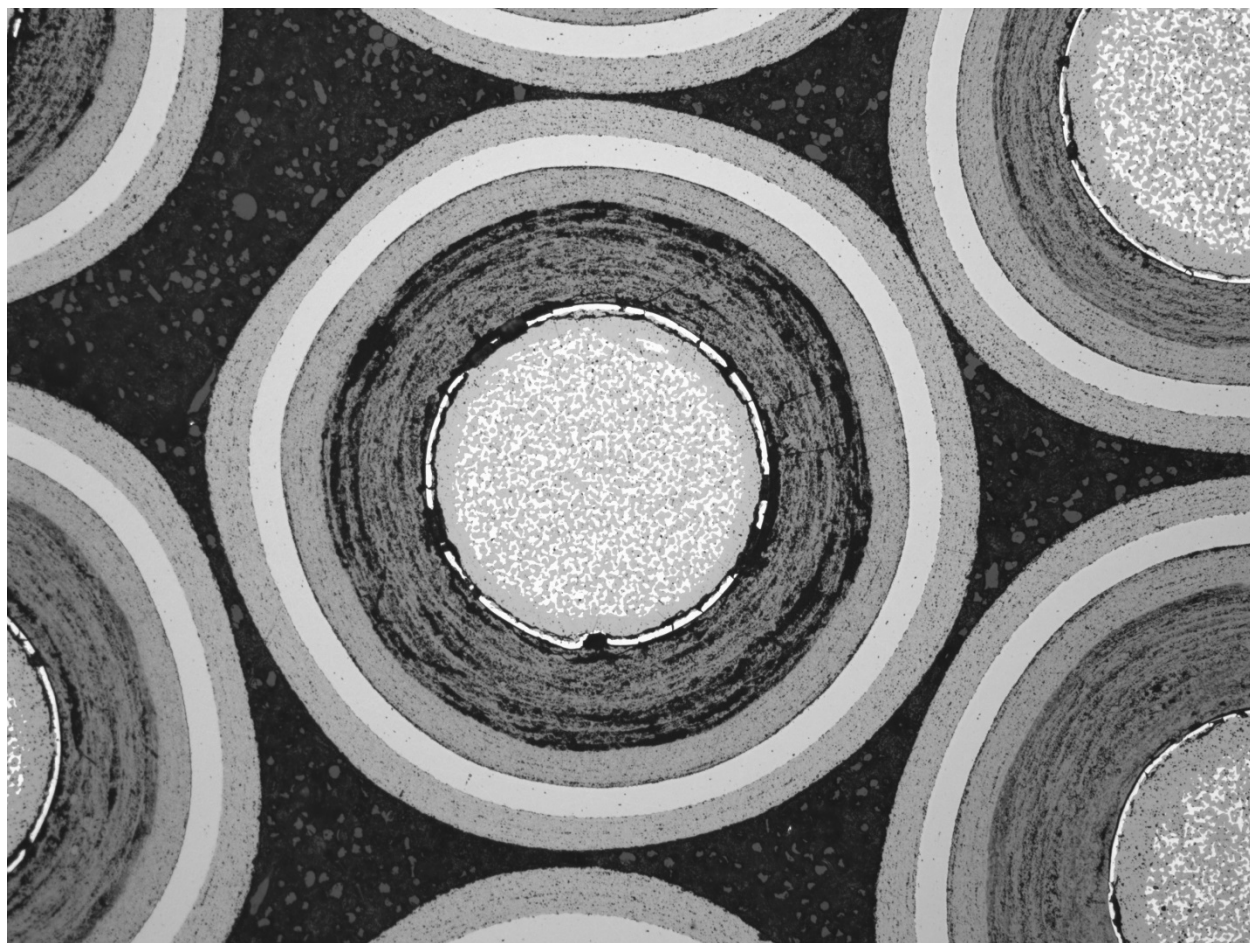


P16082301N219

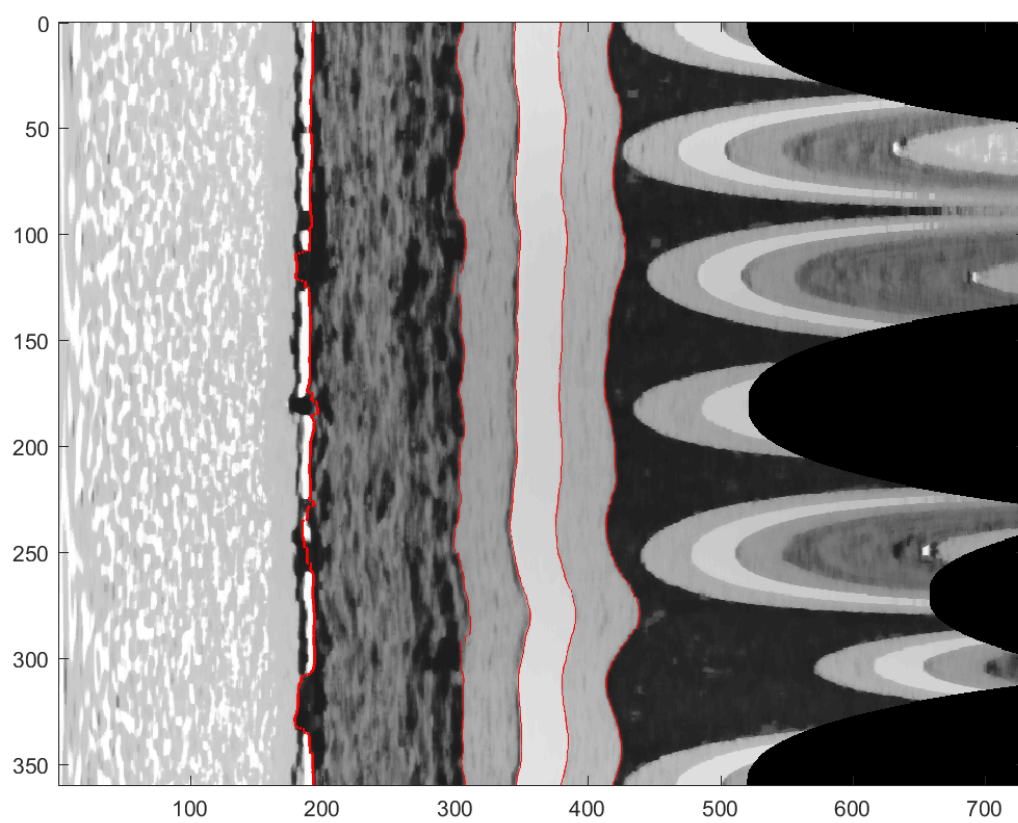


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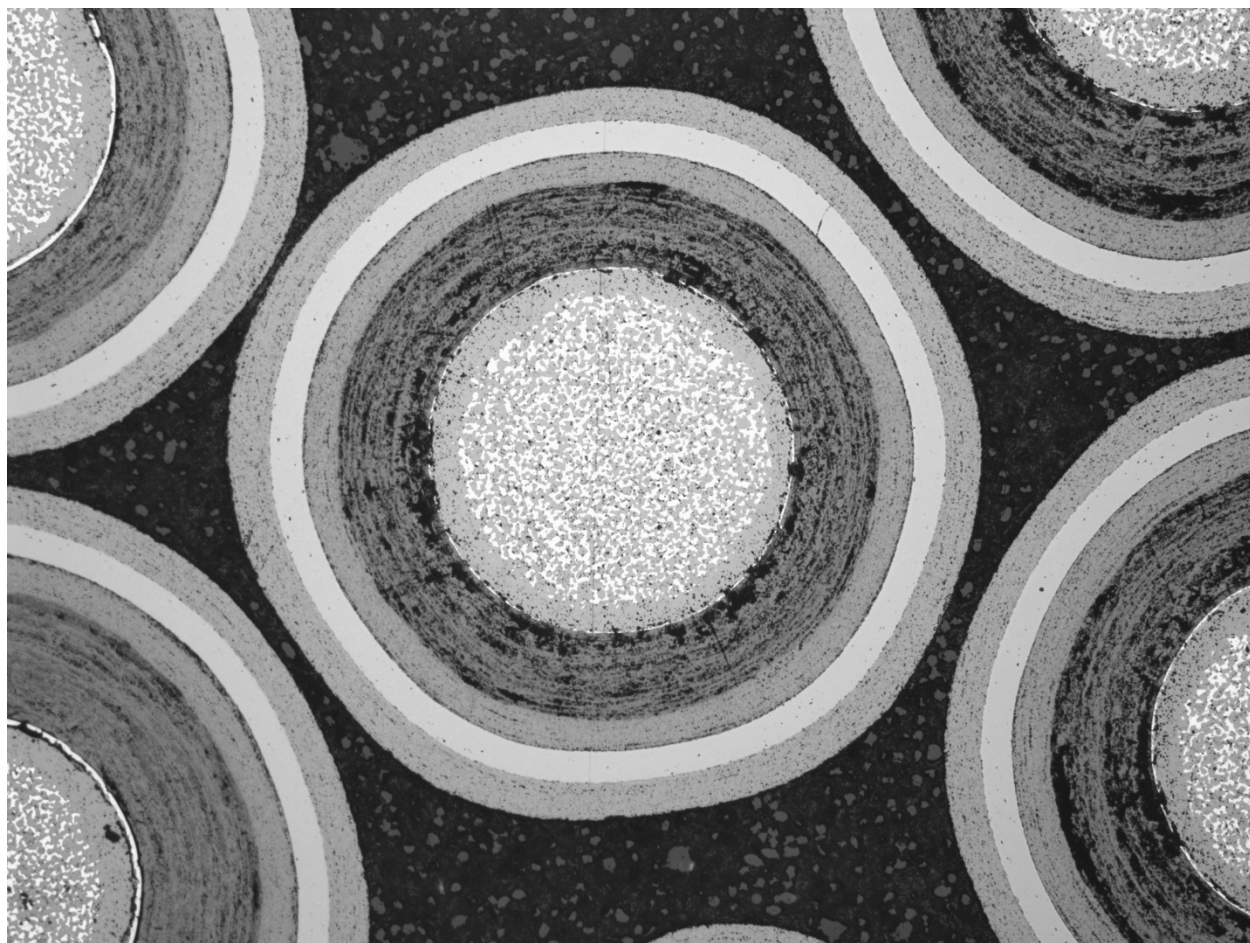




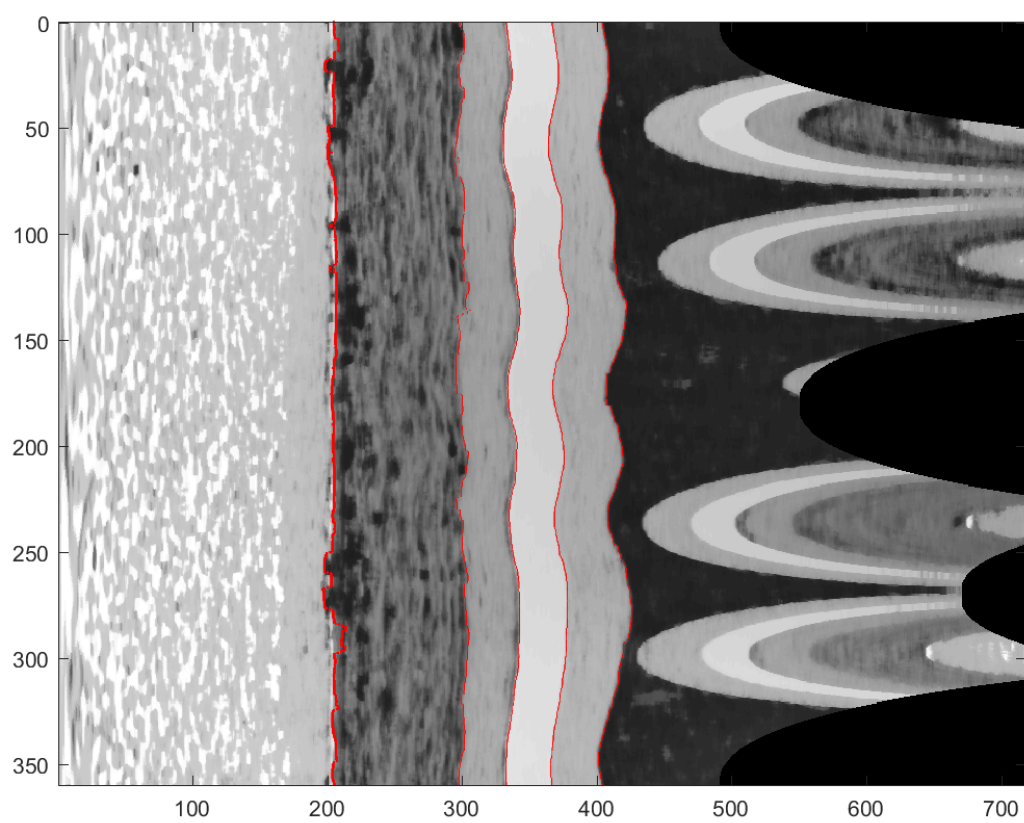
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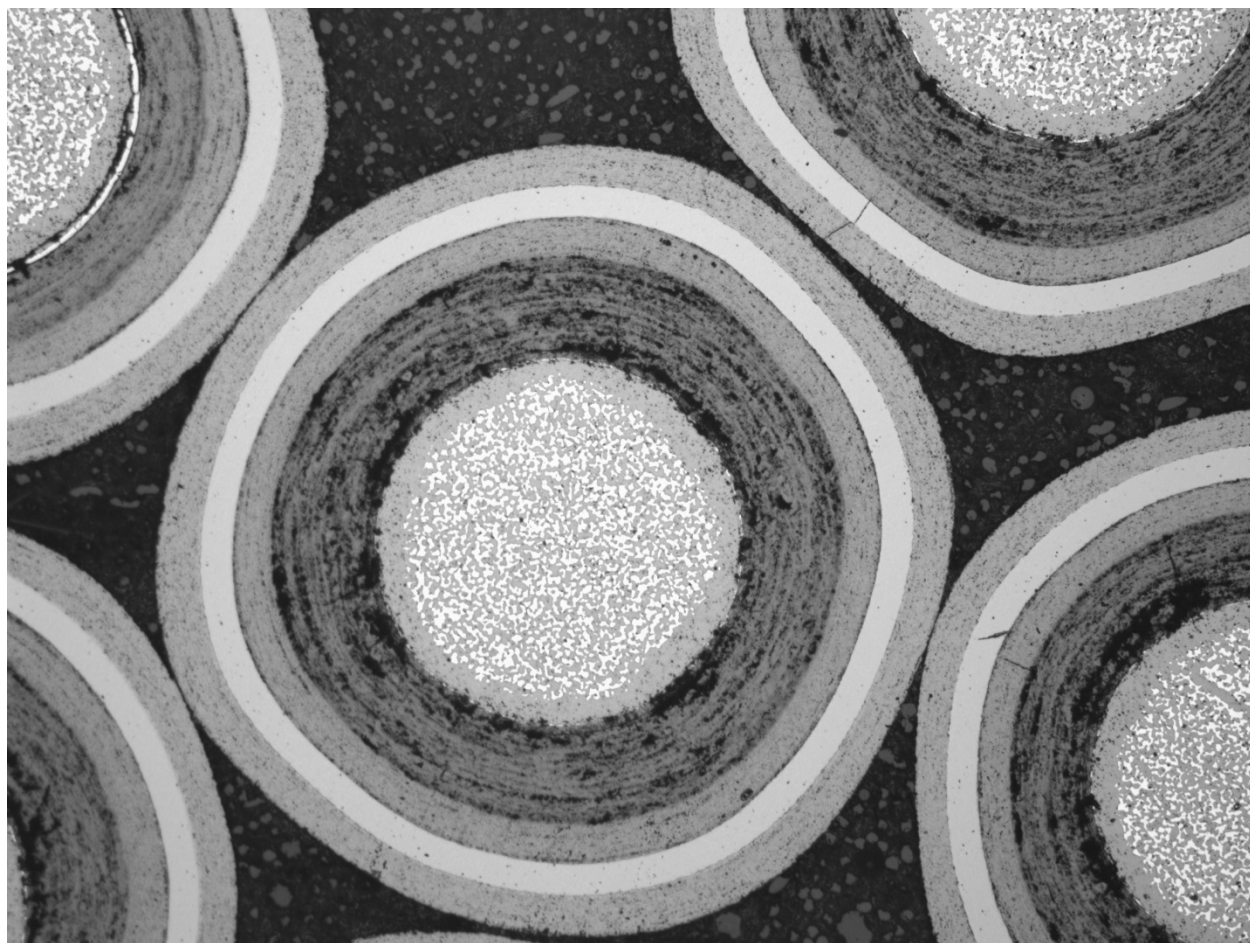
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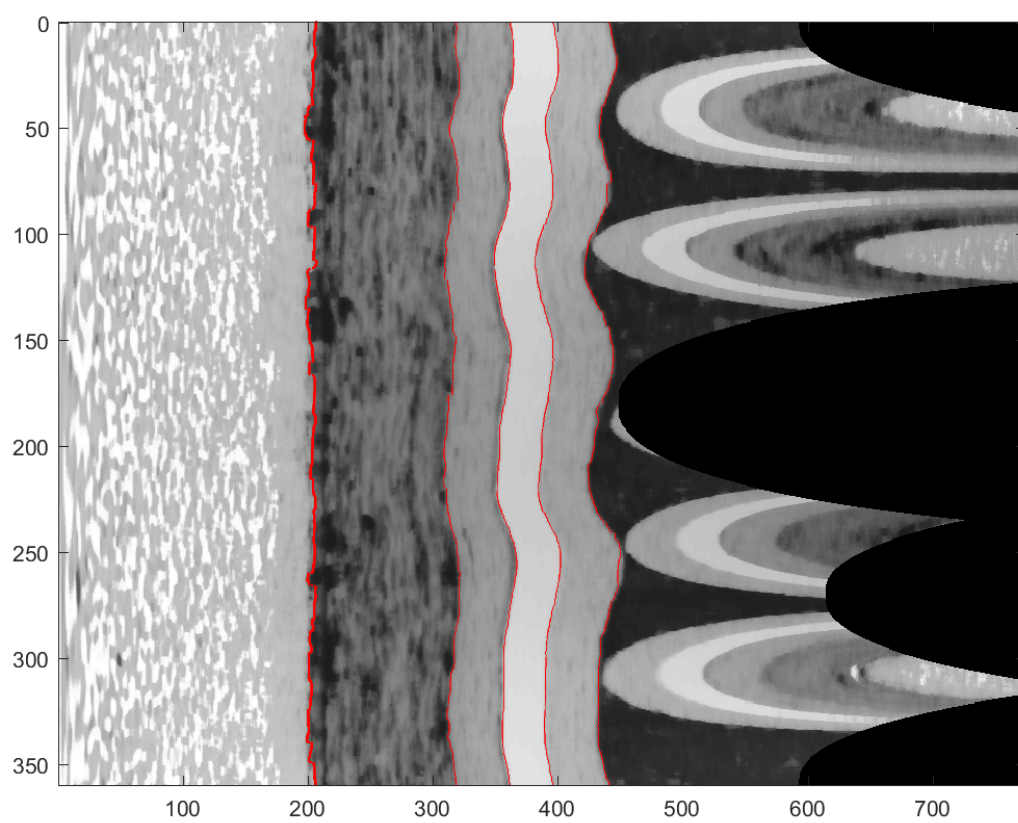
P16082301N221



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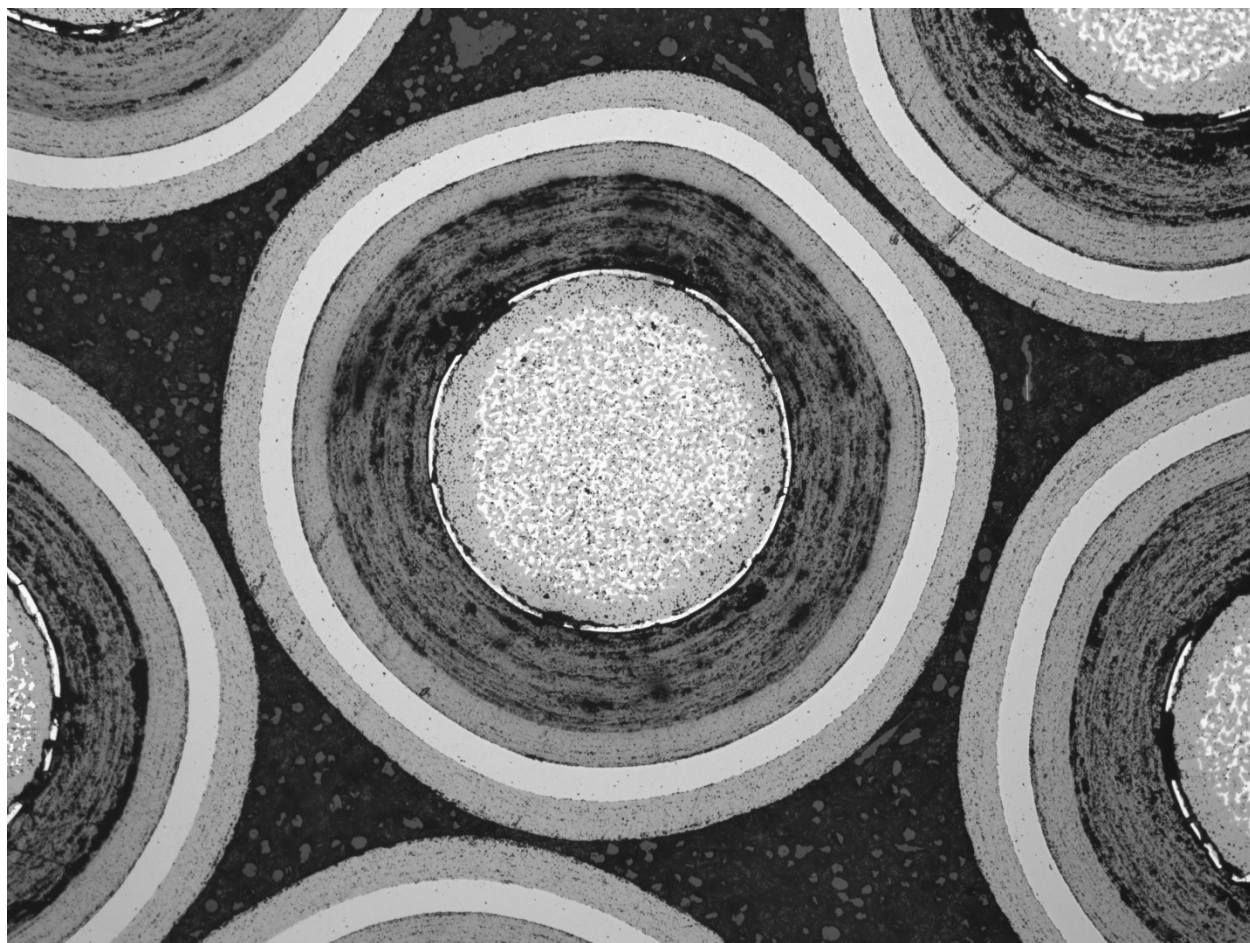


P16082301N222

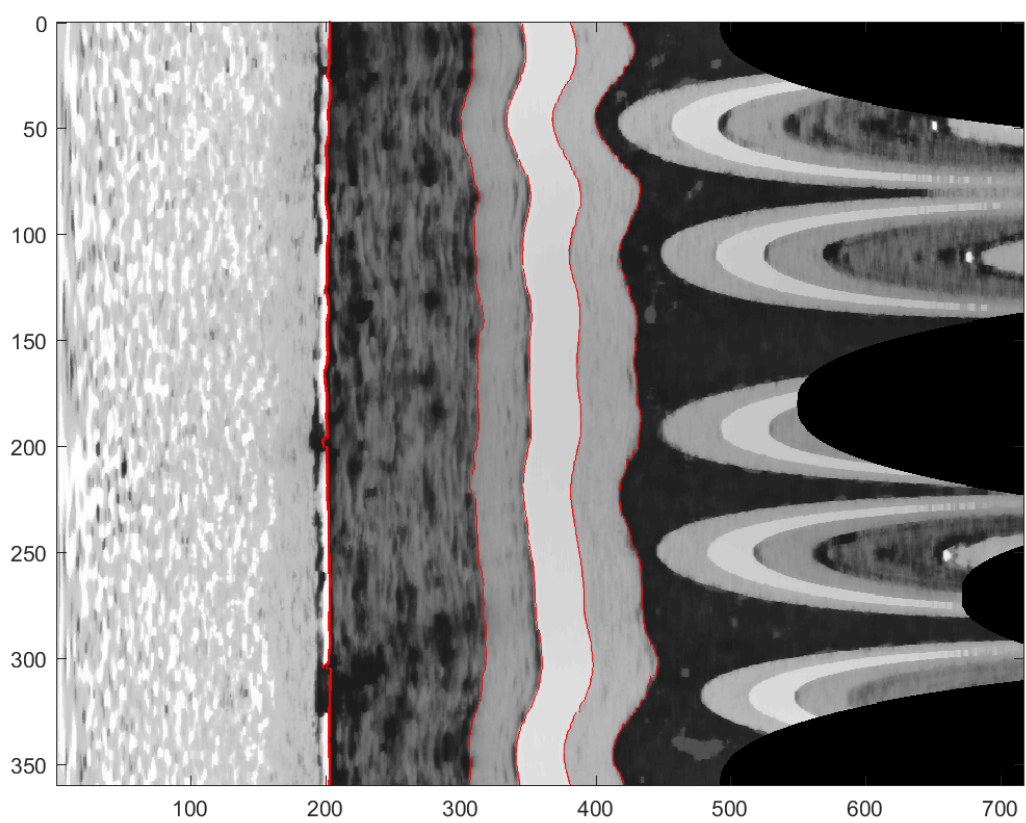


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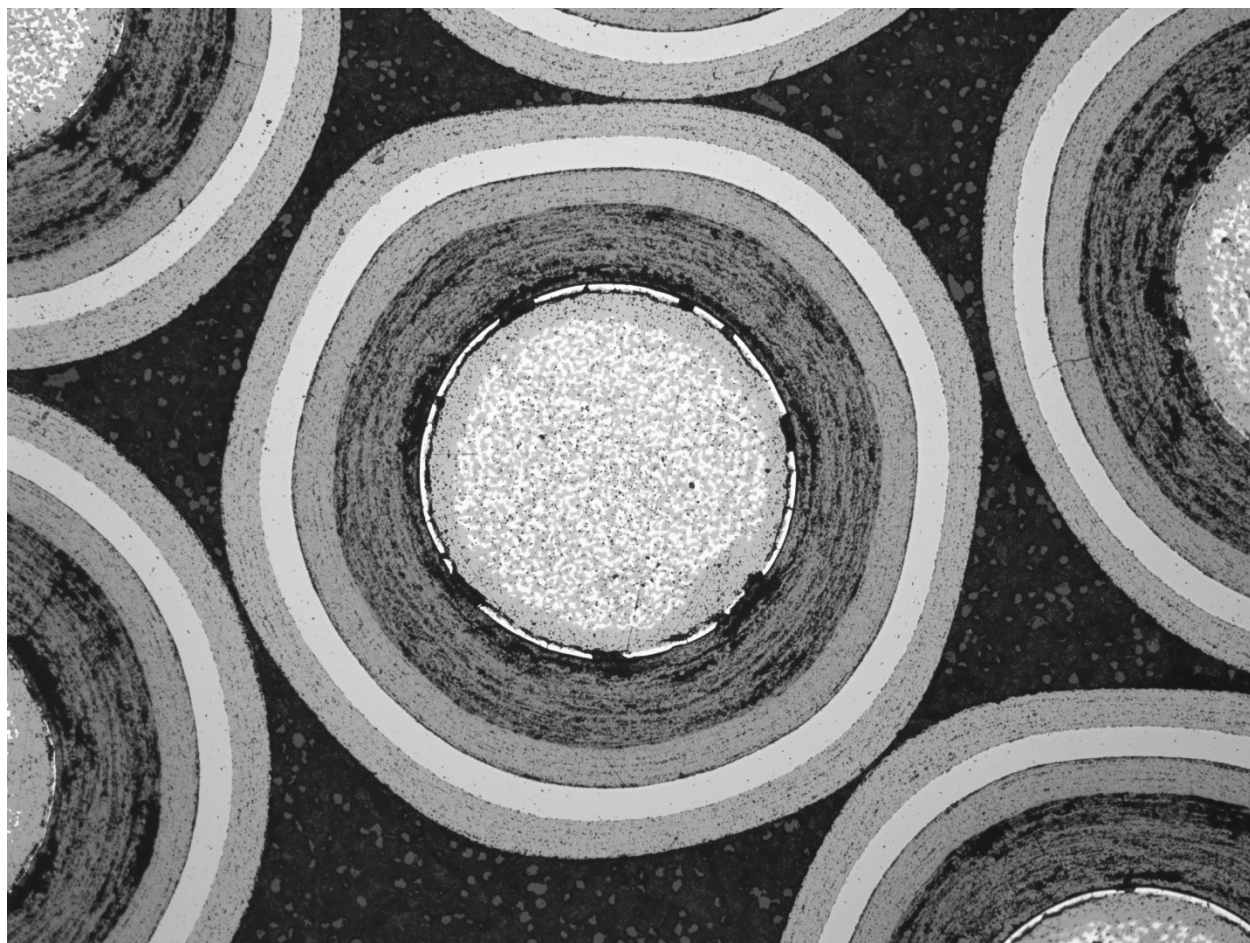




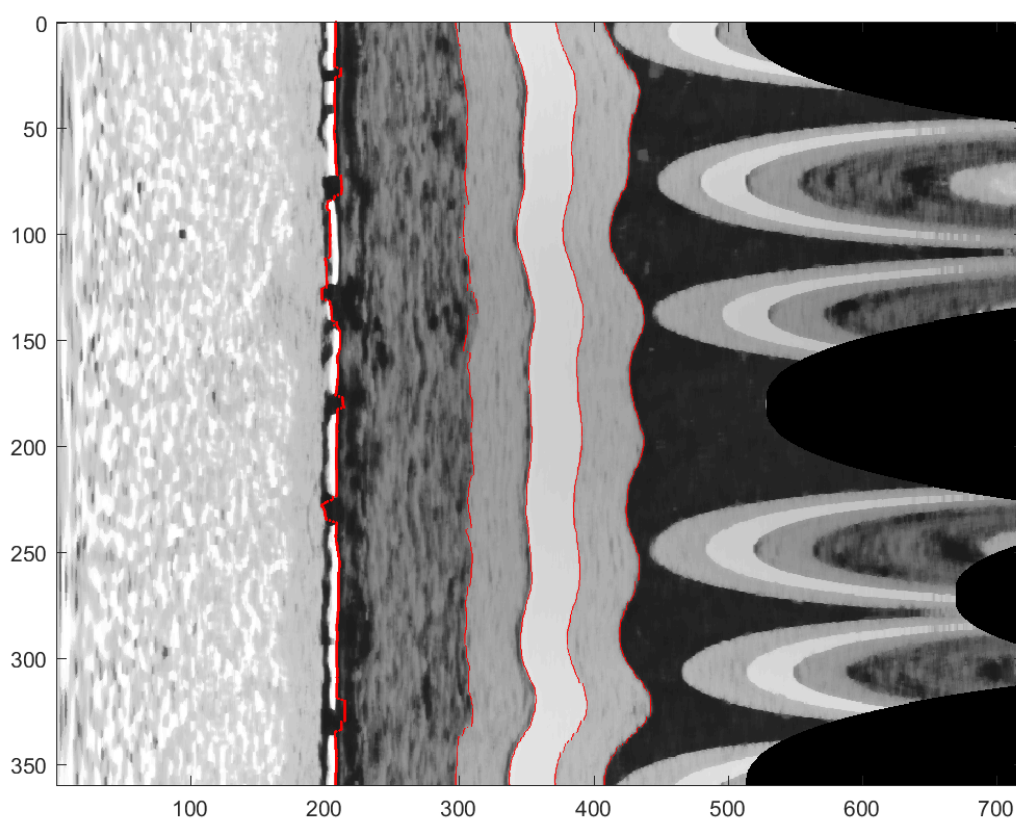
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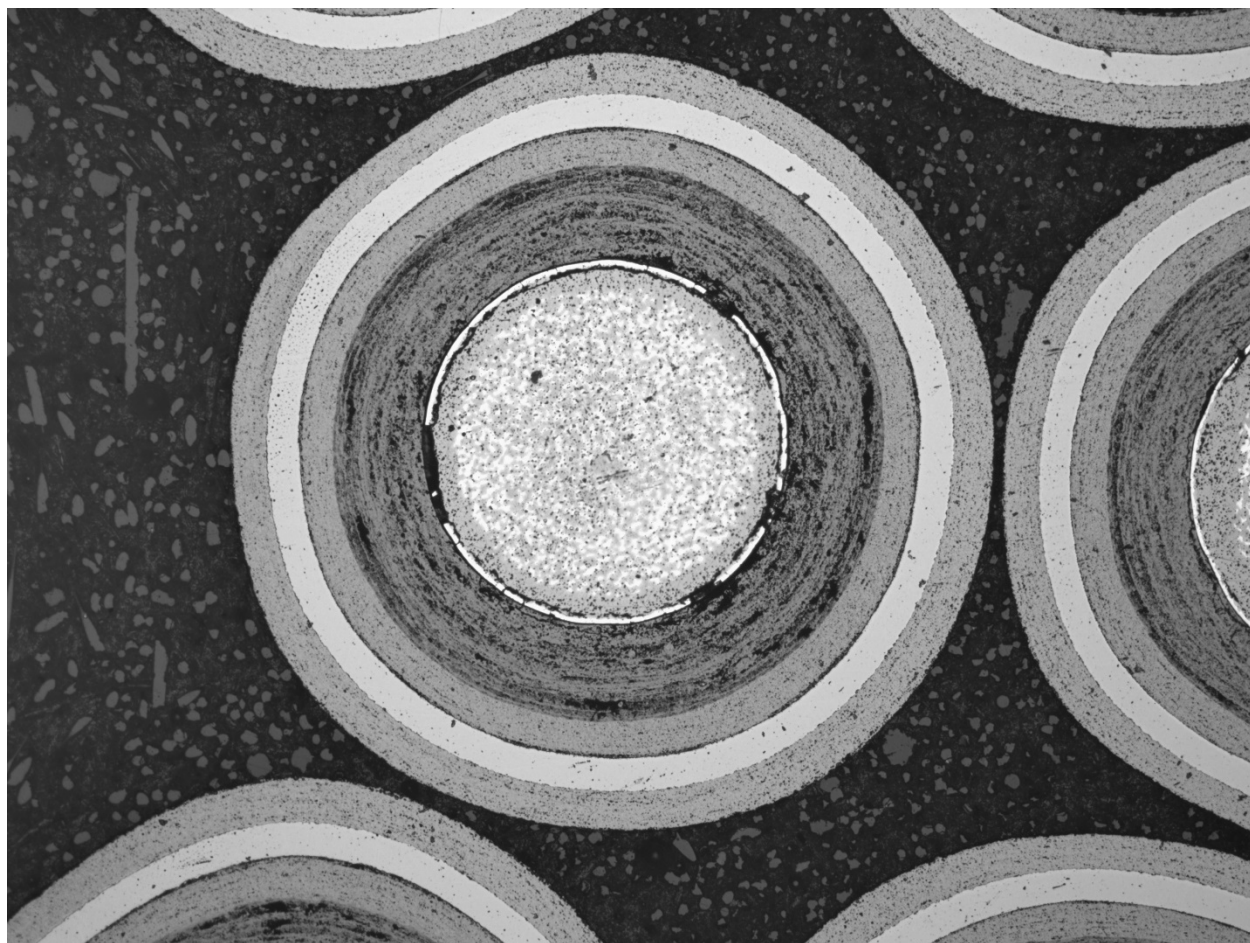
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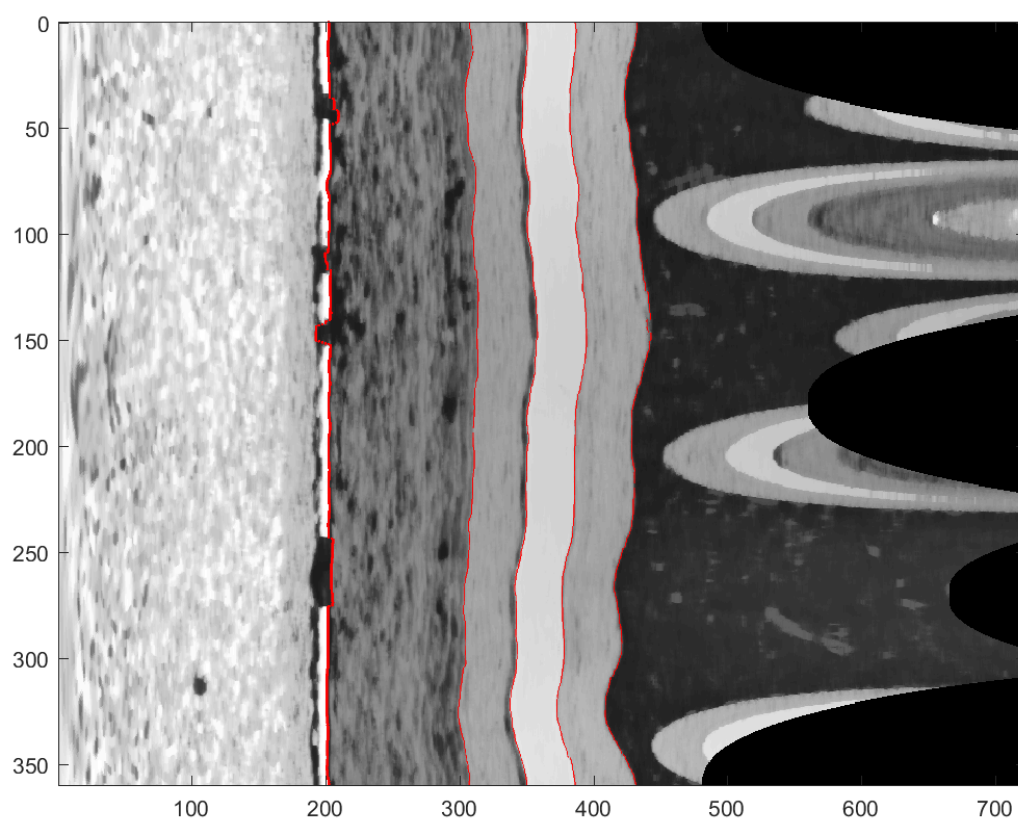
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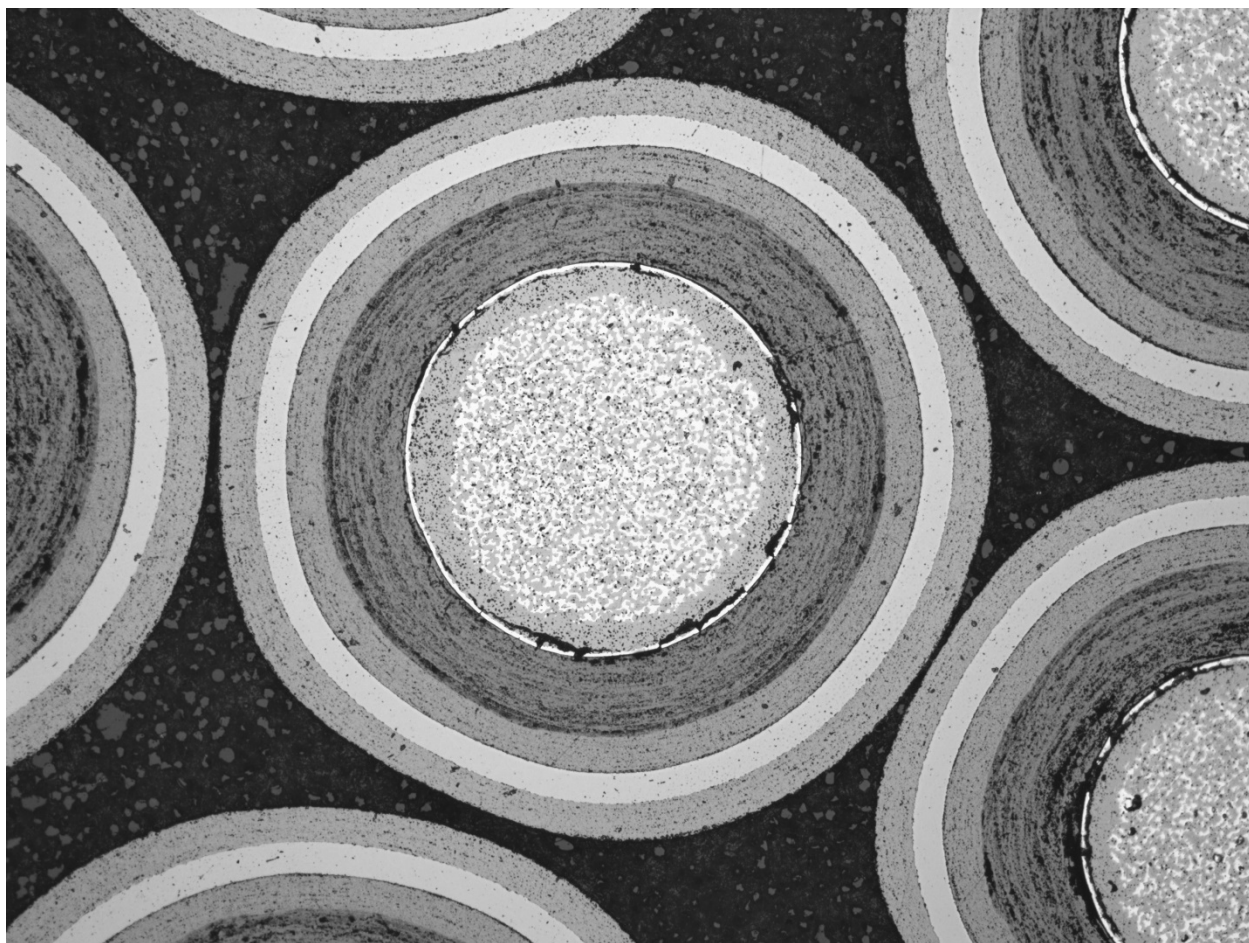


P16082301N225

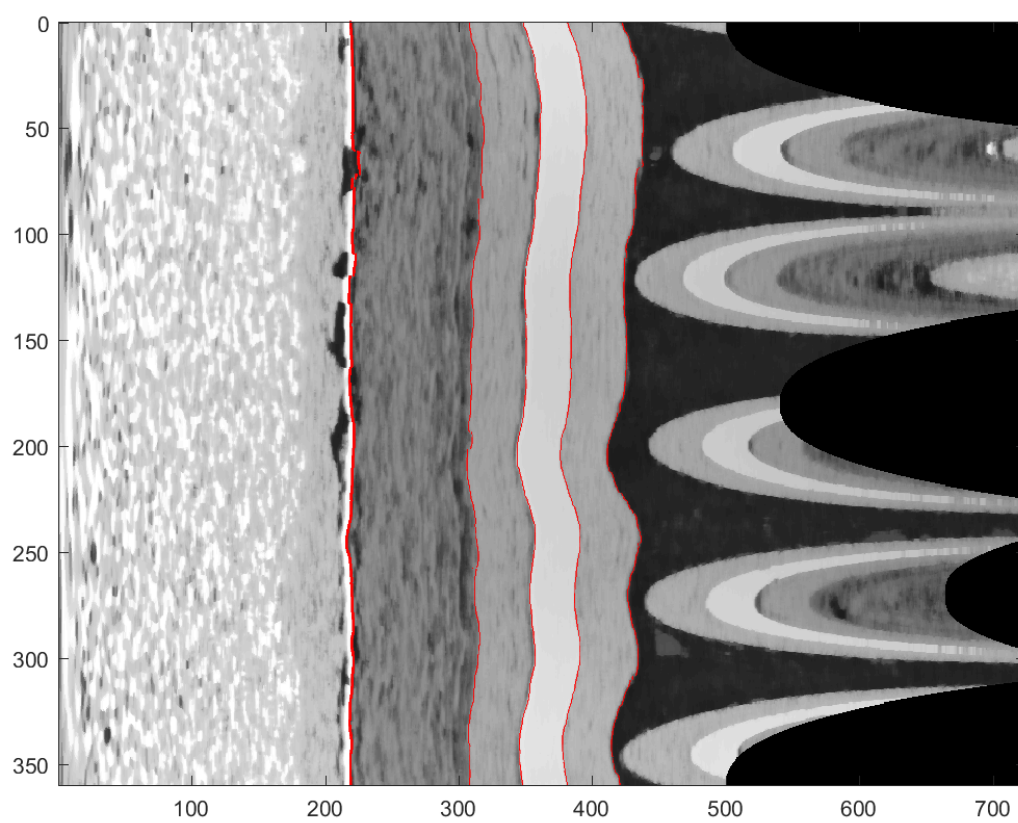


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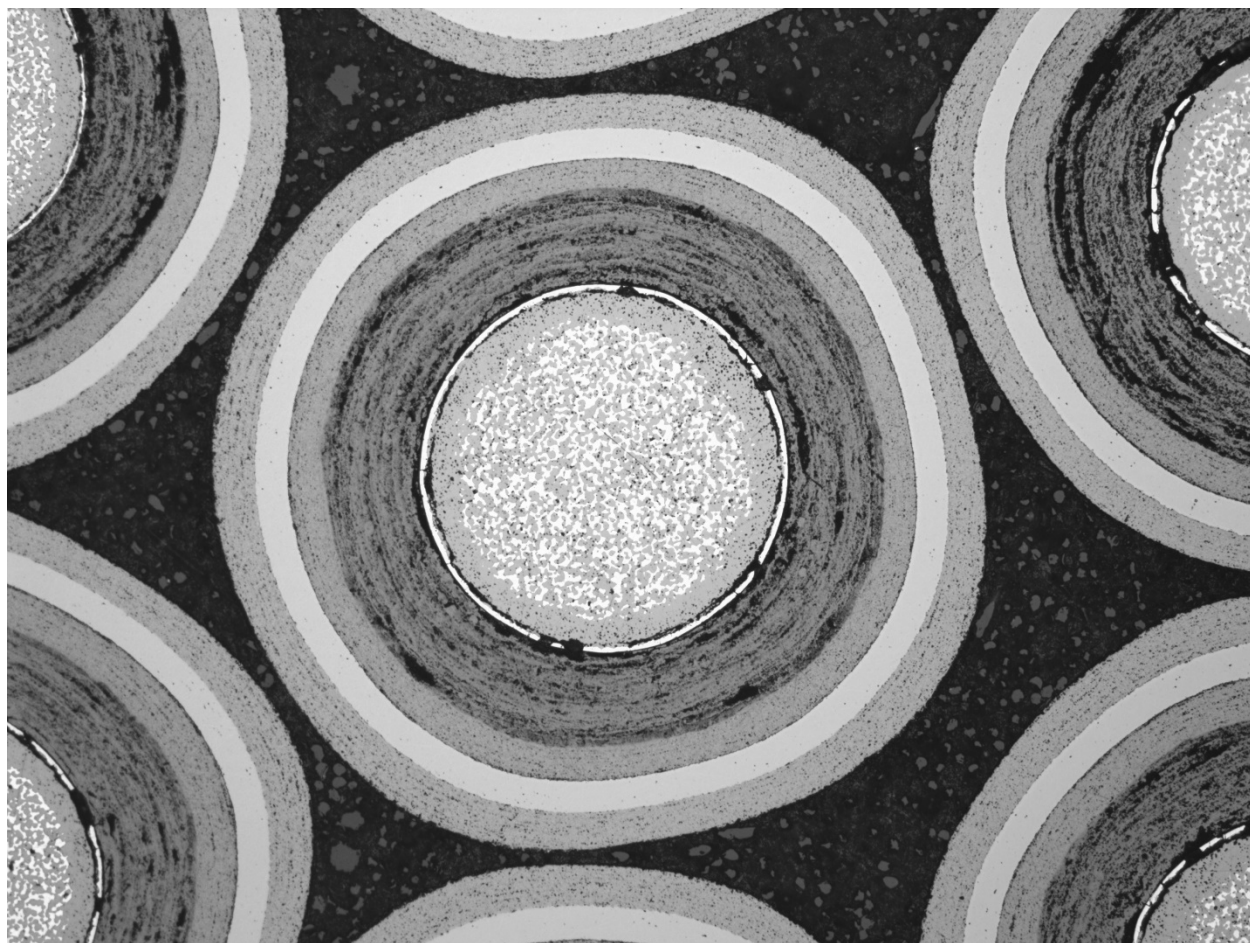




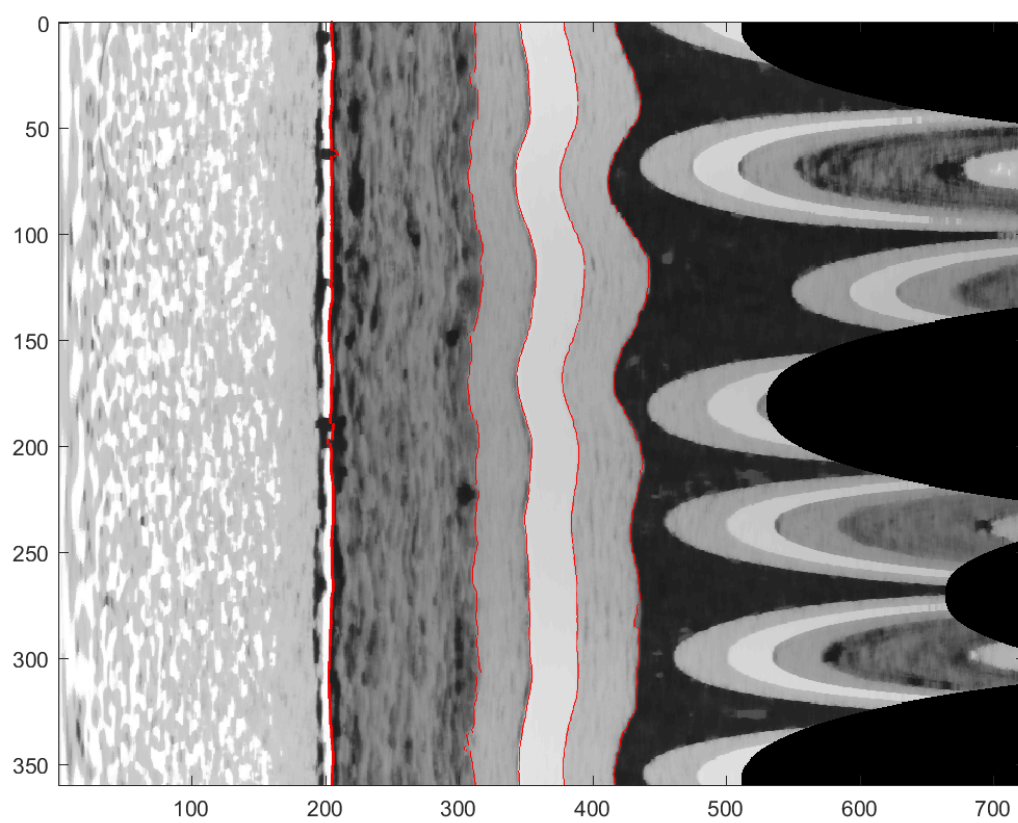
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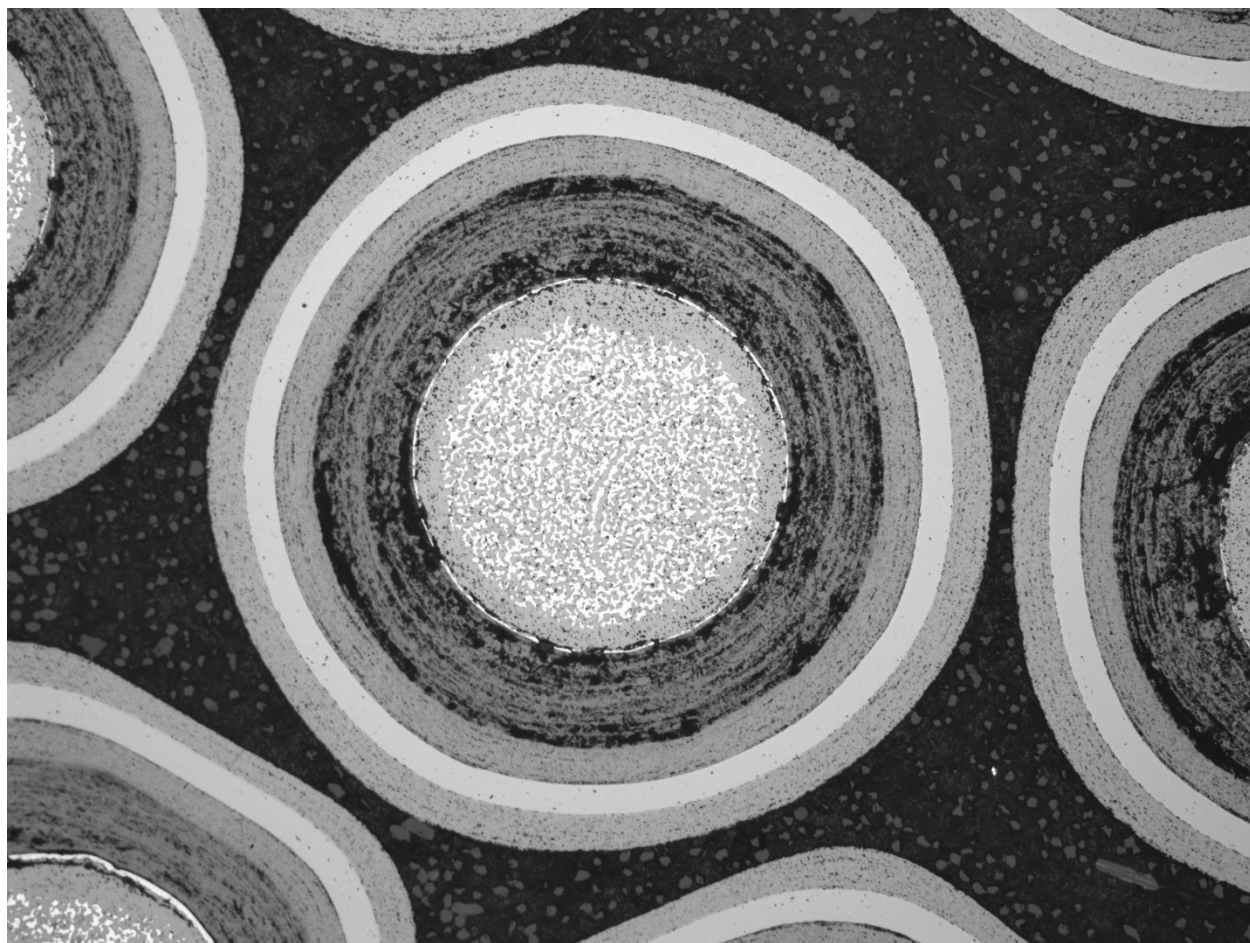
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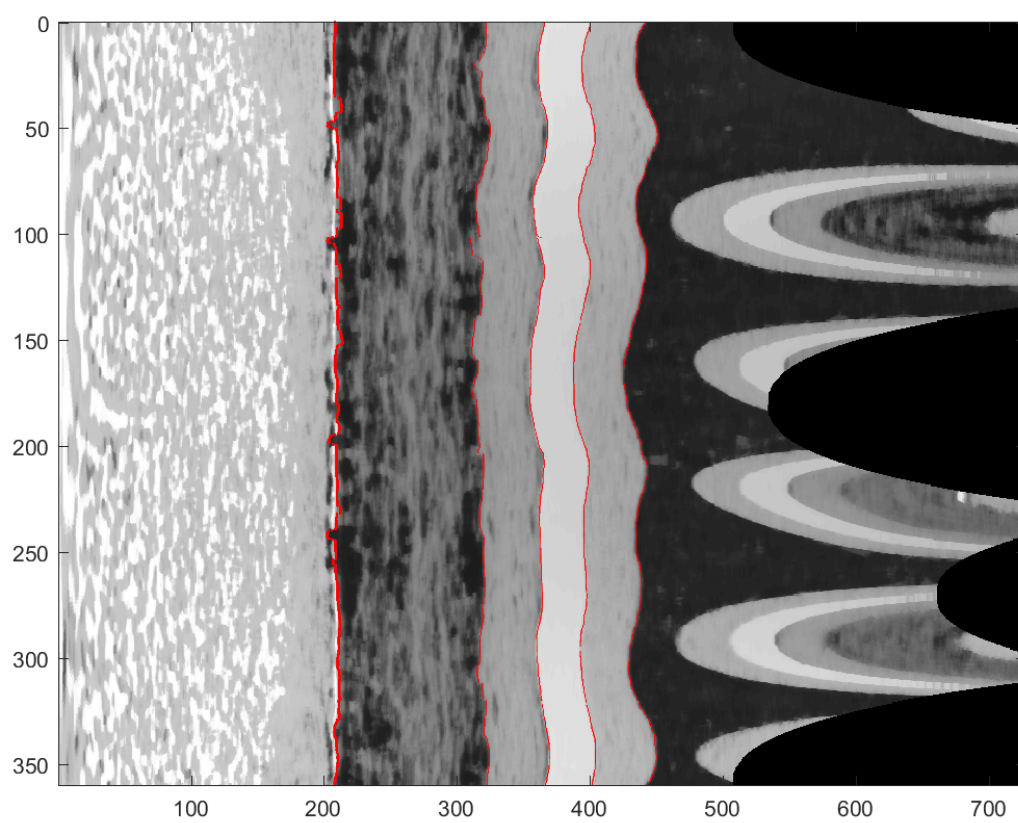
P16082301N227



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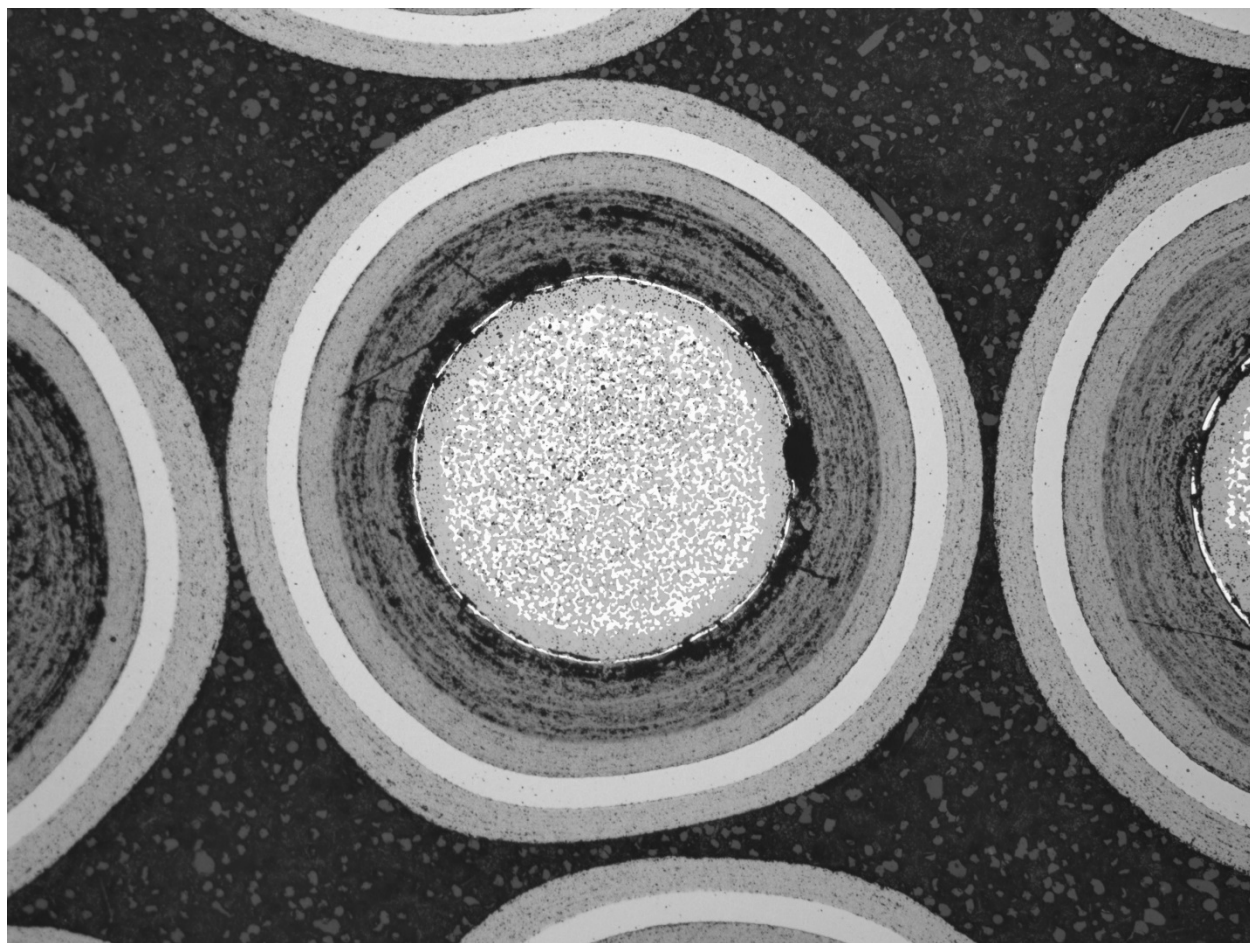


P16082301N228

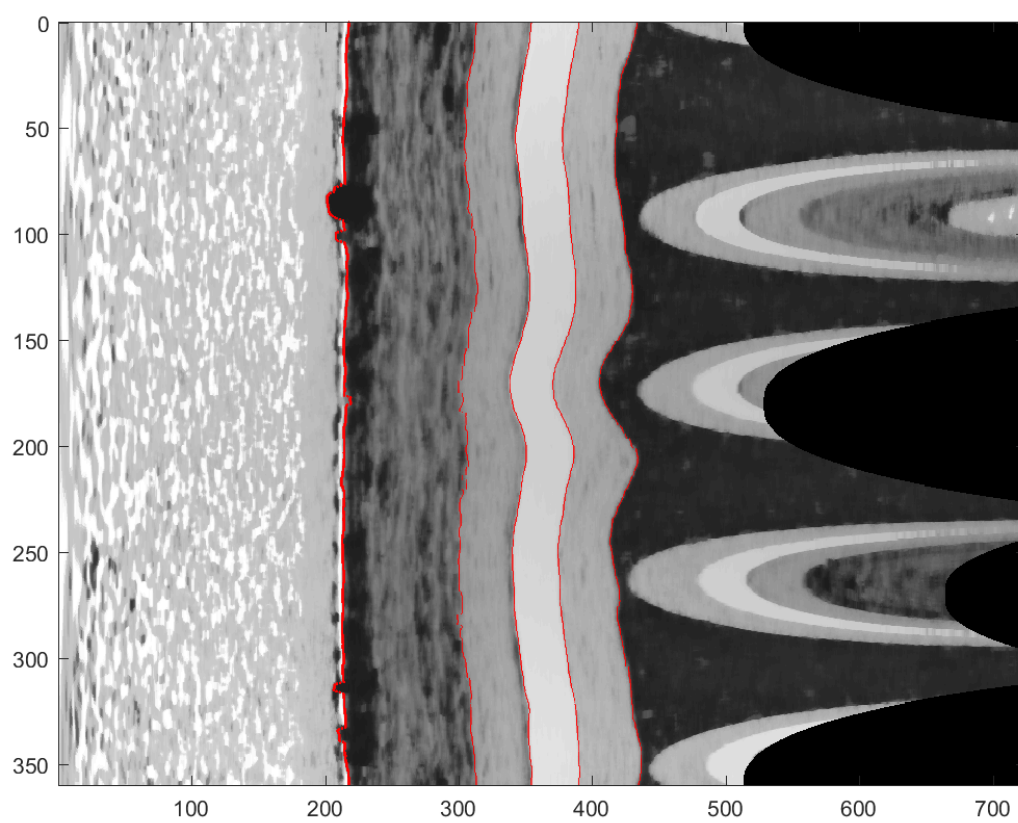


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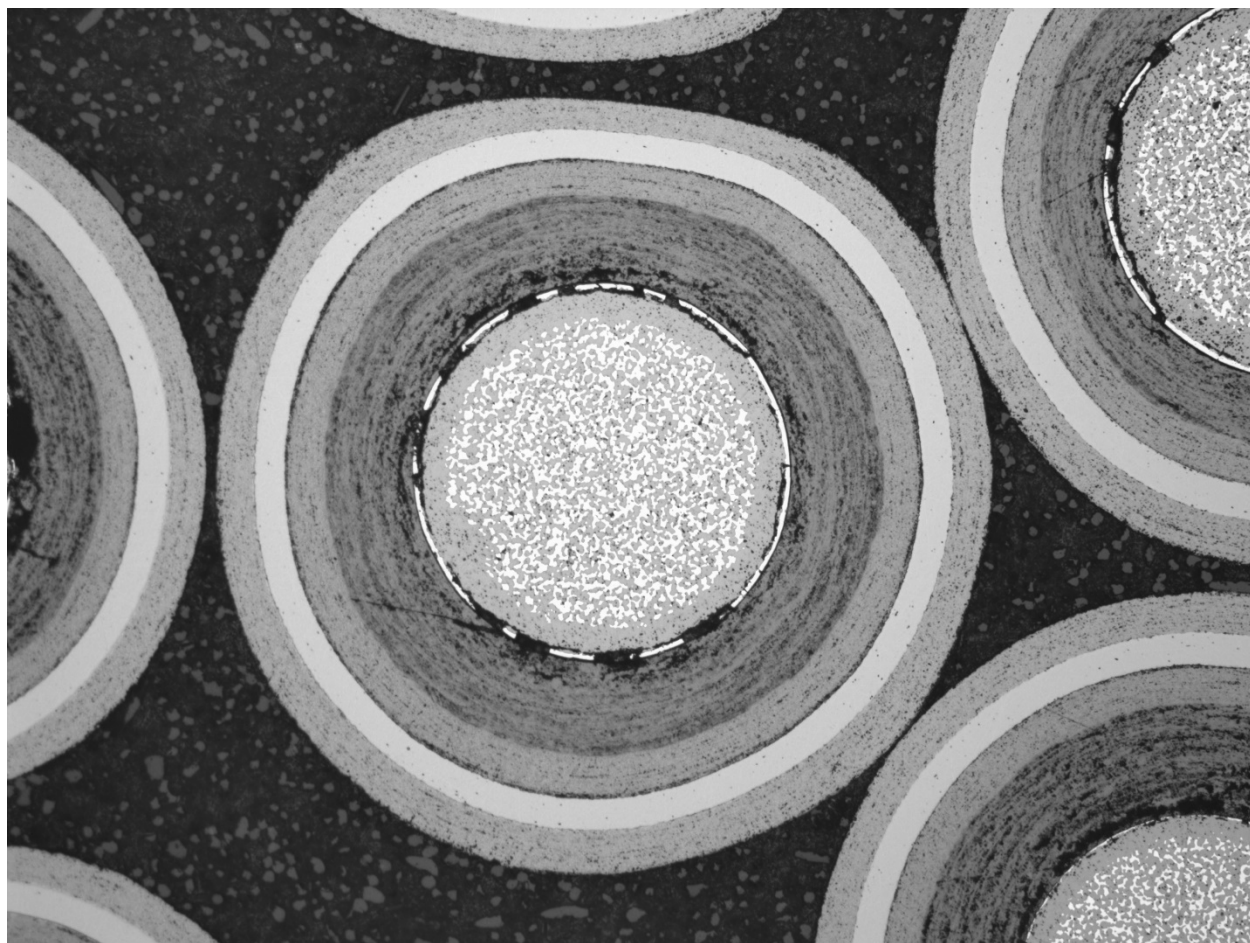




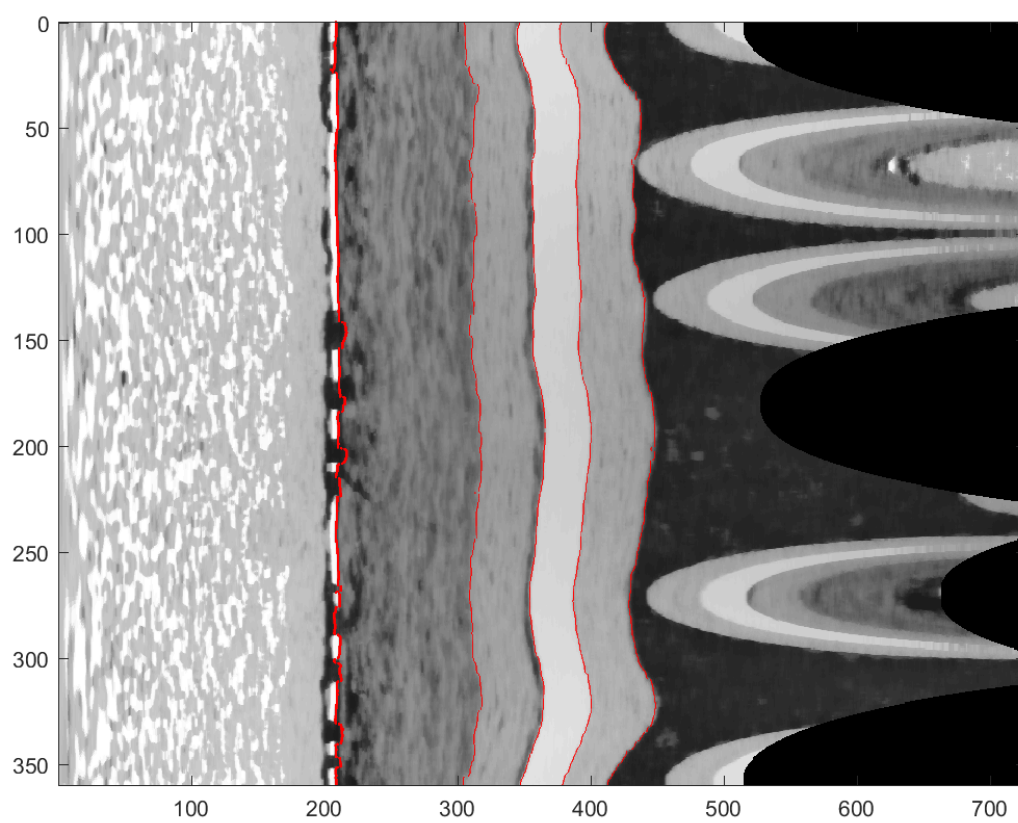
P16082301N229



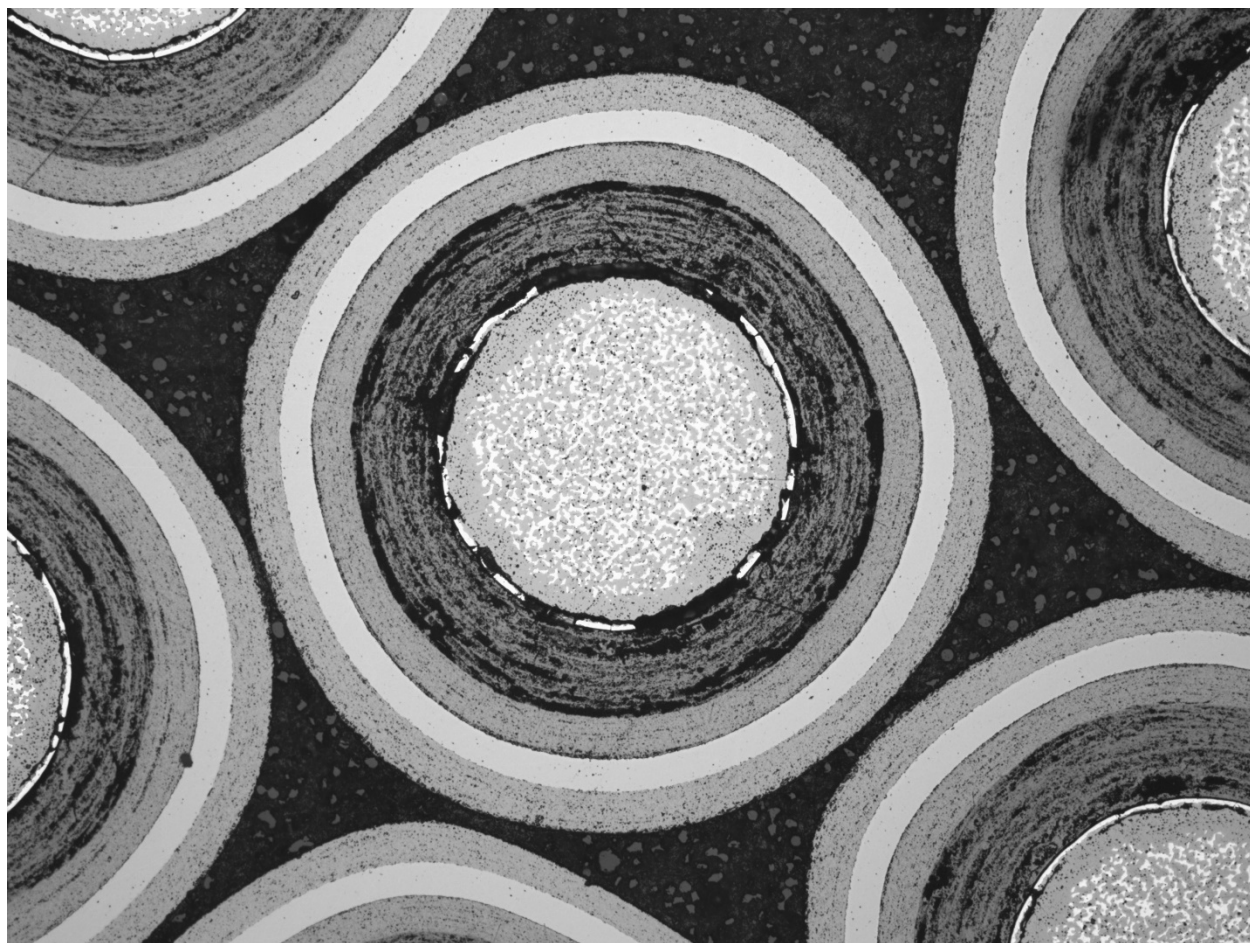
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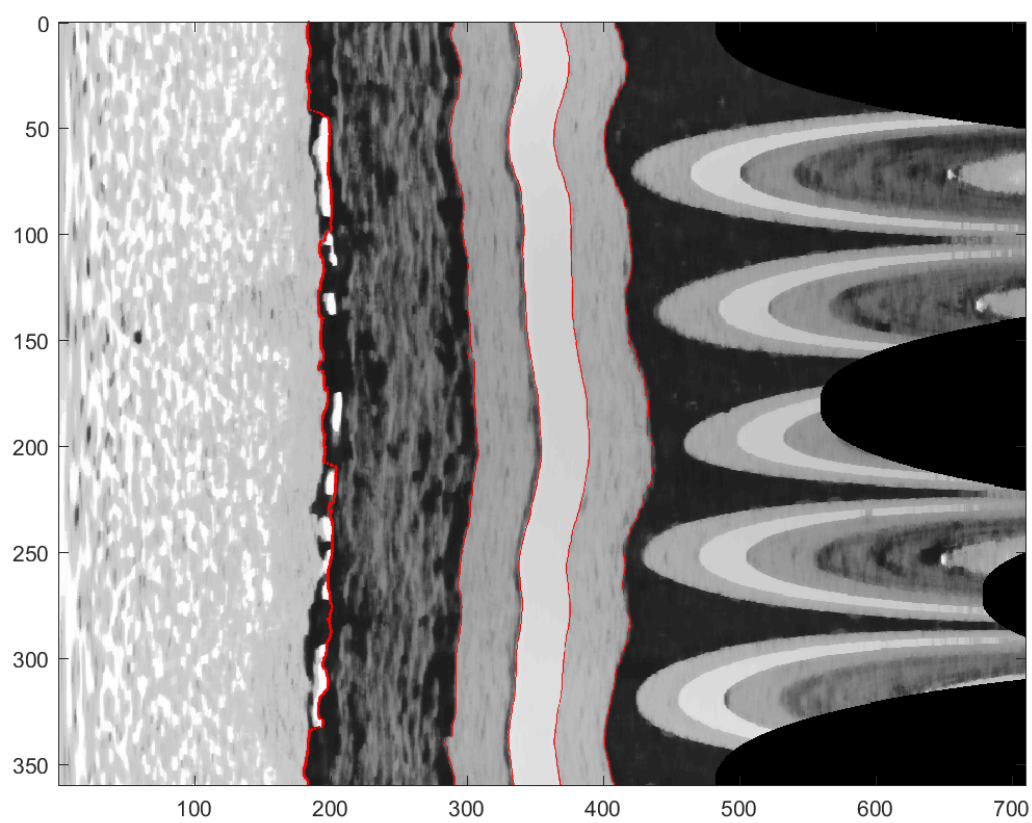
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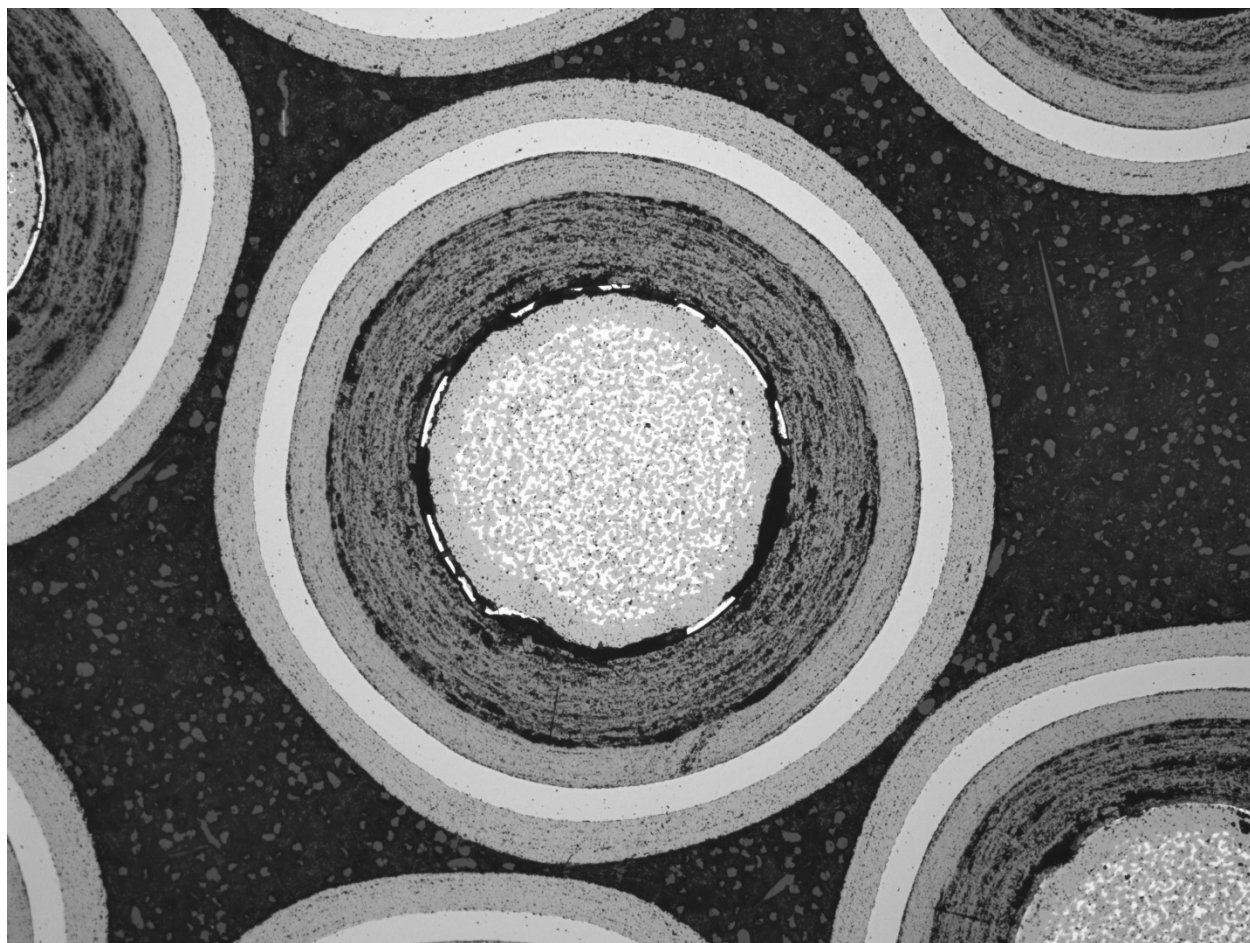


P16082301N231

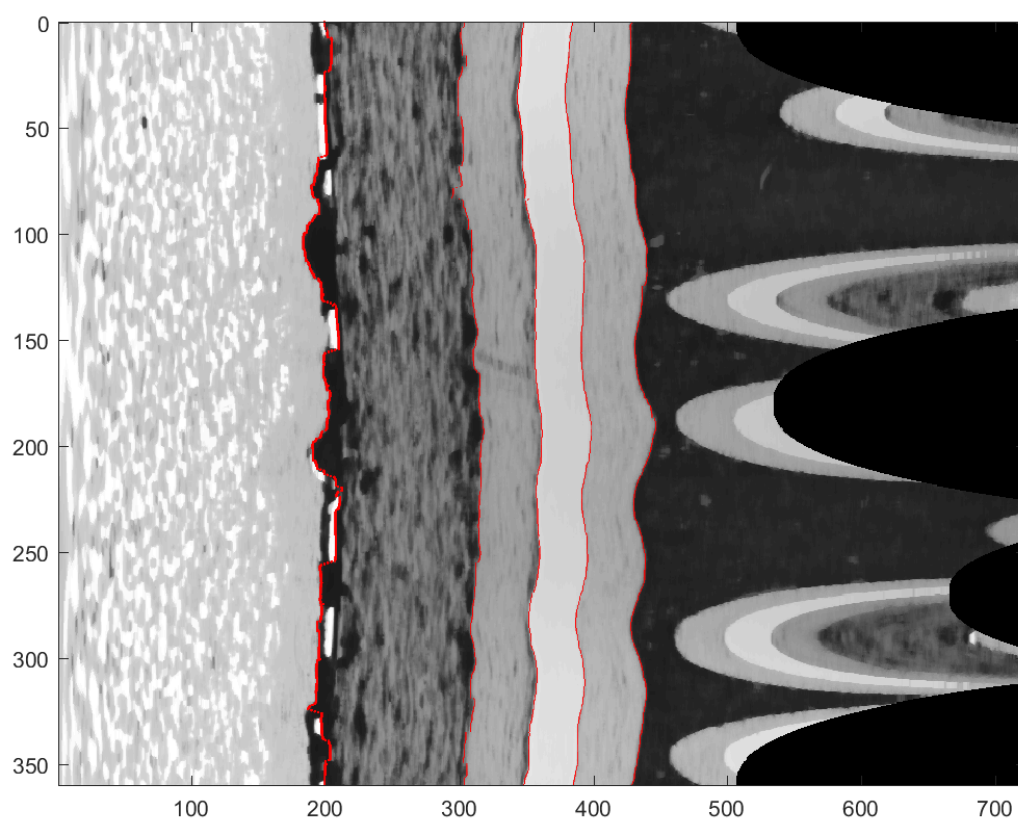


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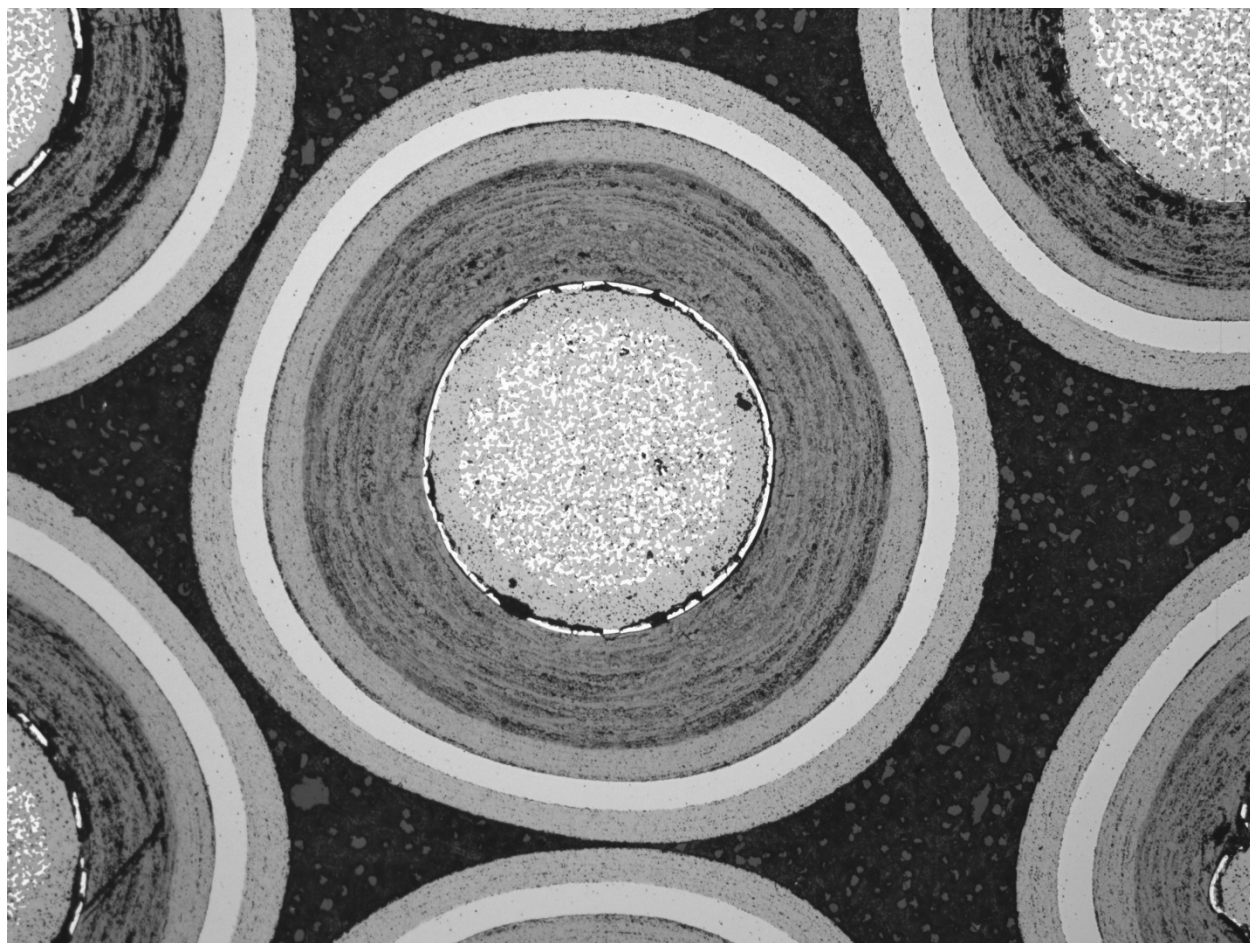




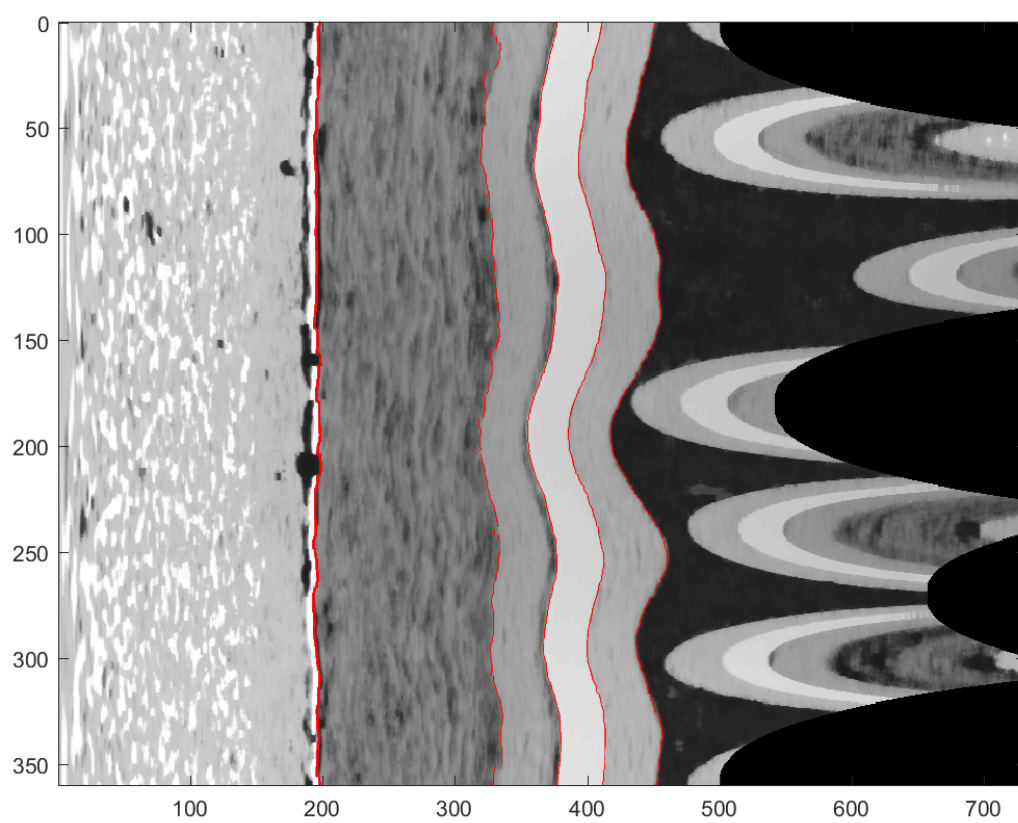
P16082301N232



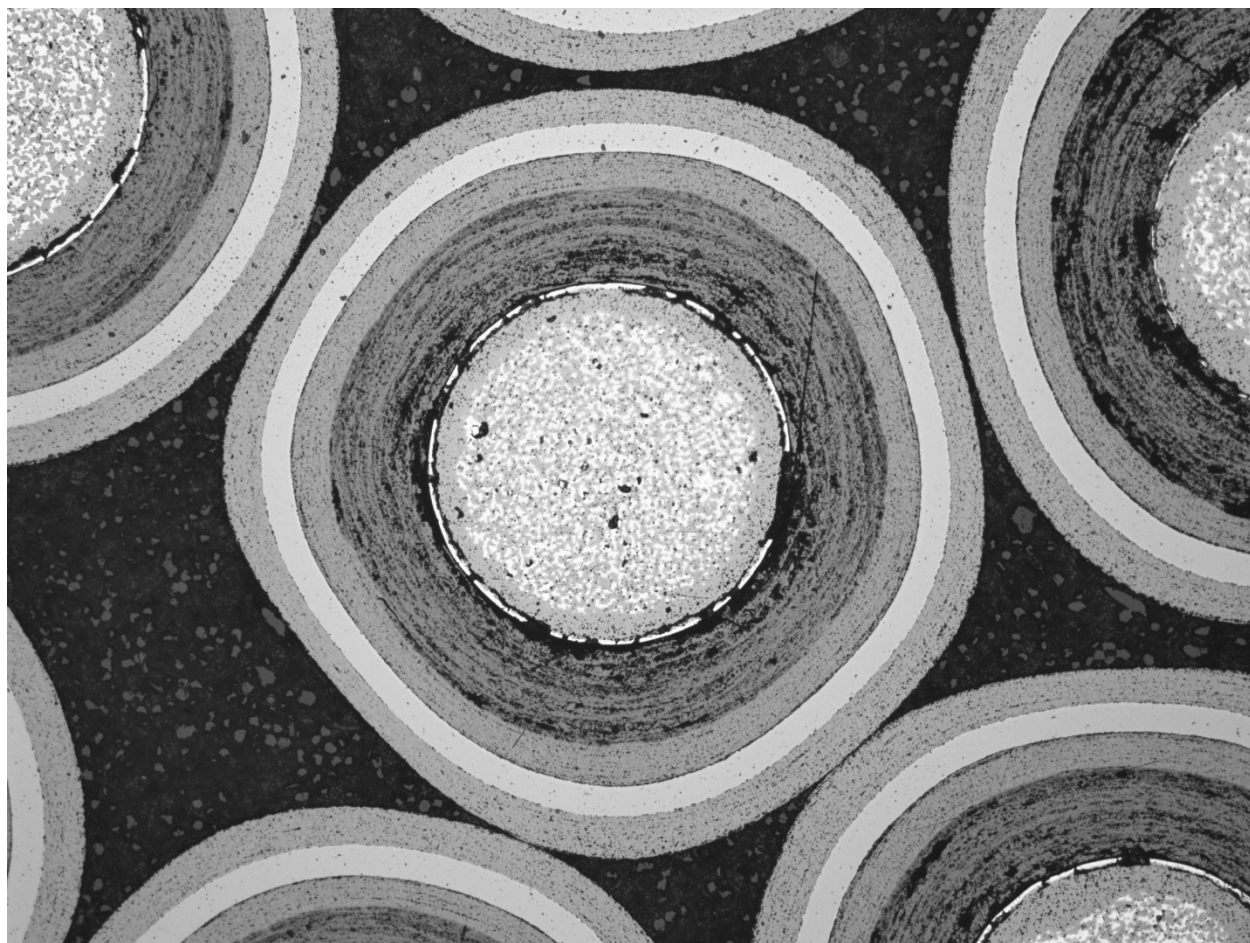
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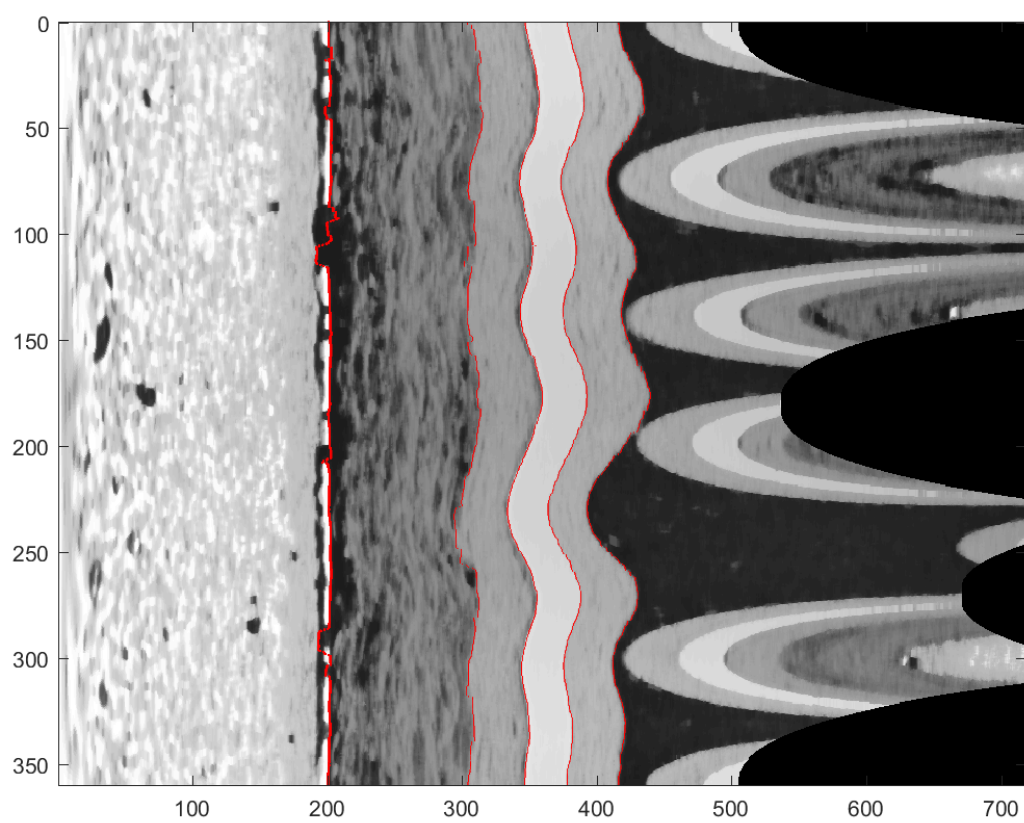
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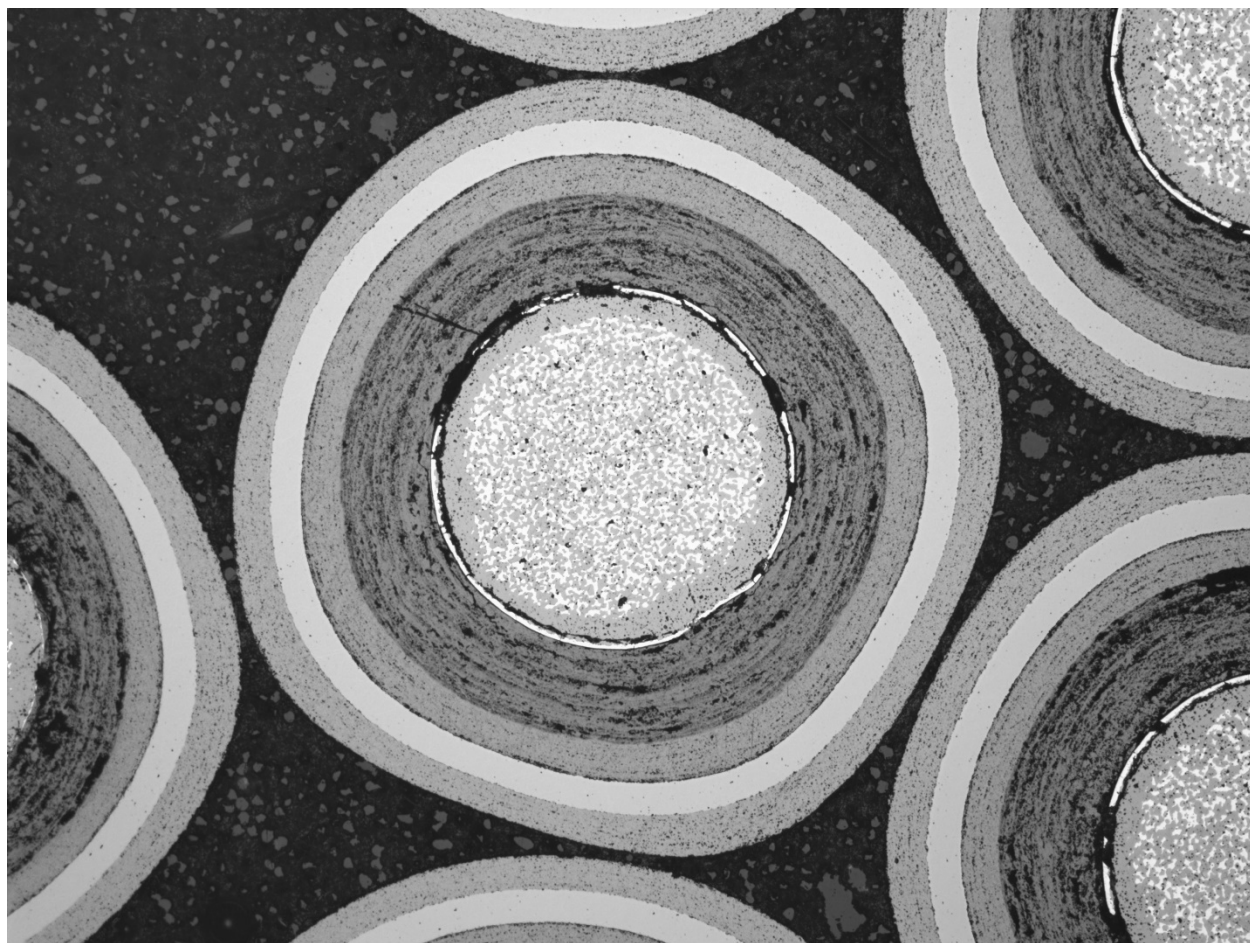


P16082301N235

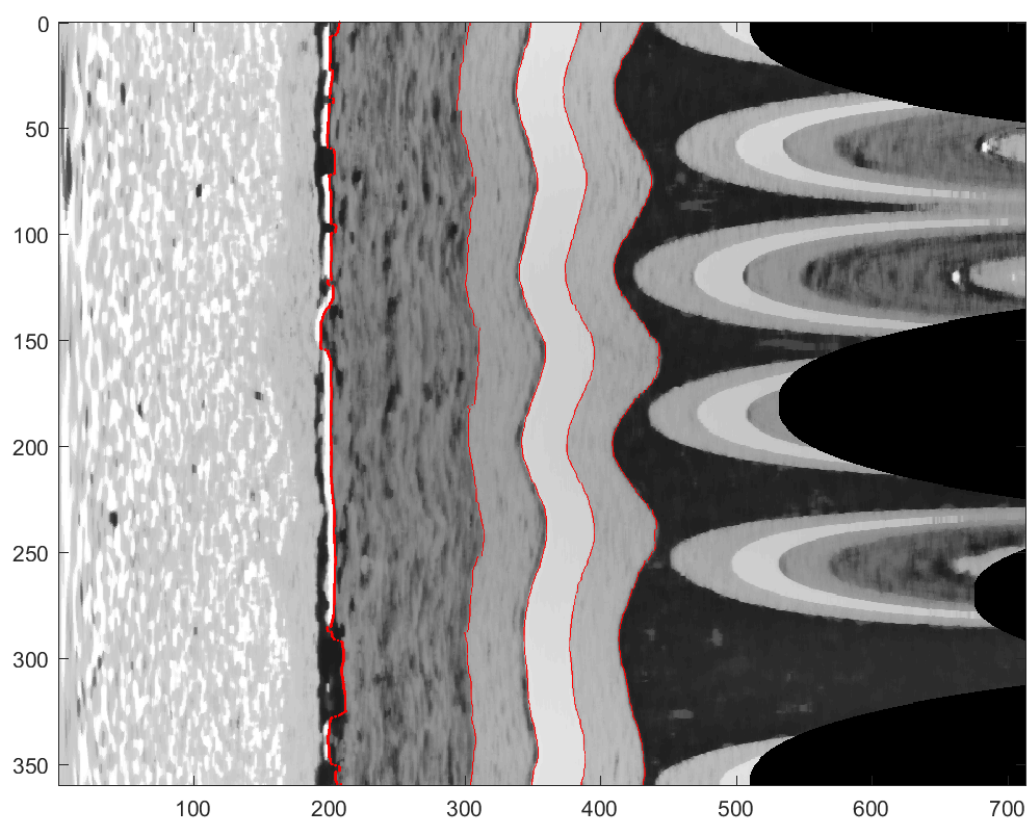


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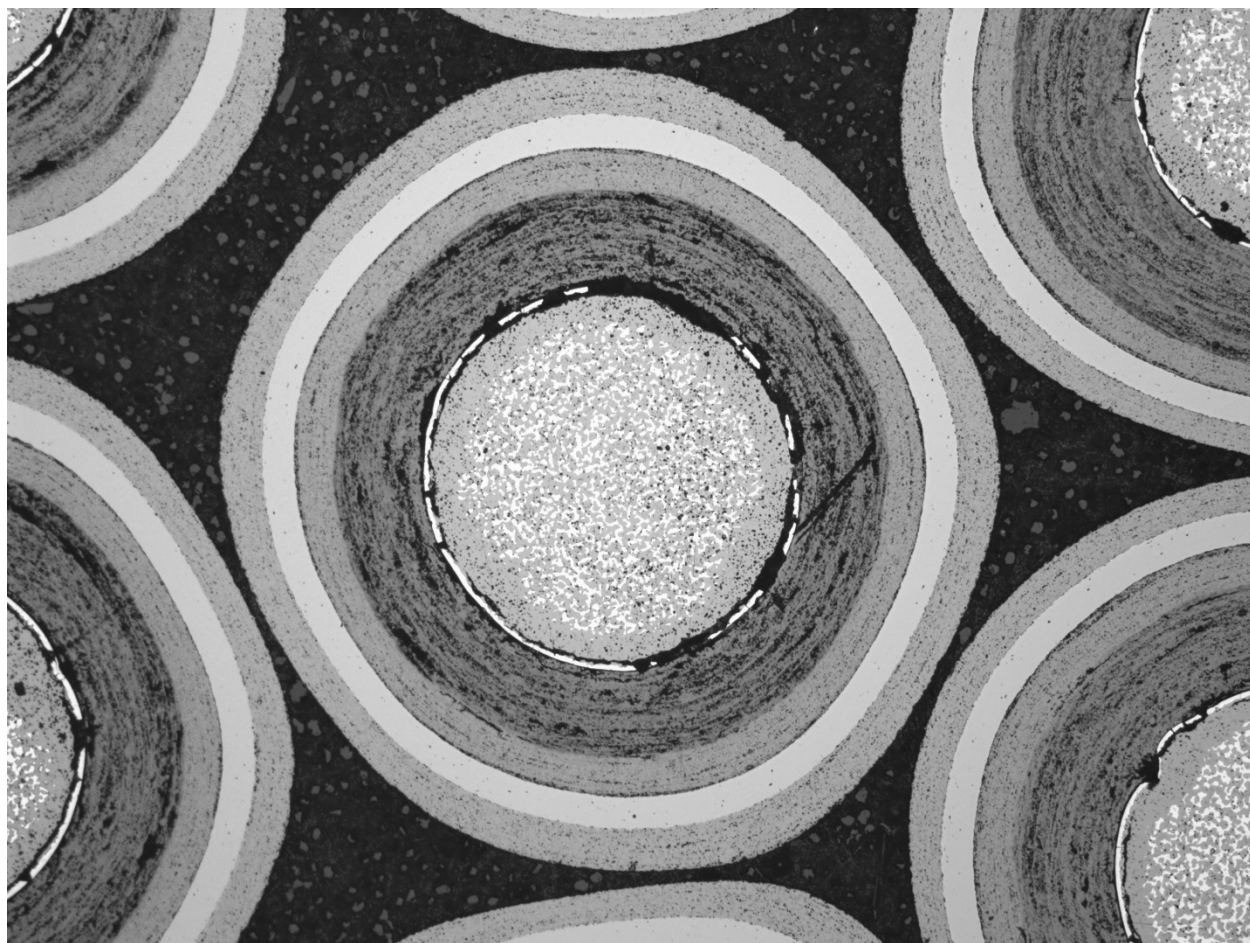




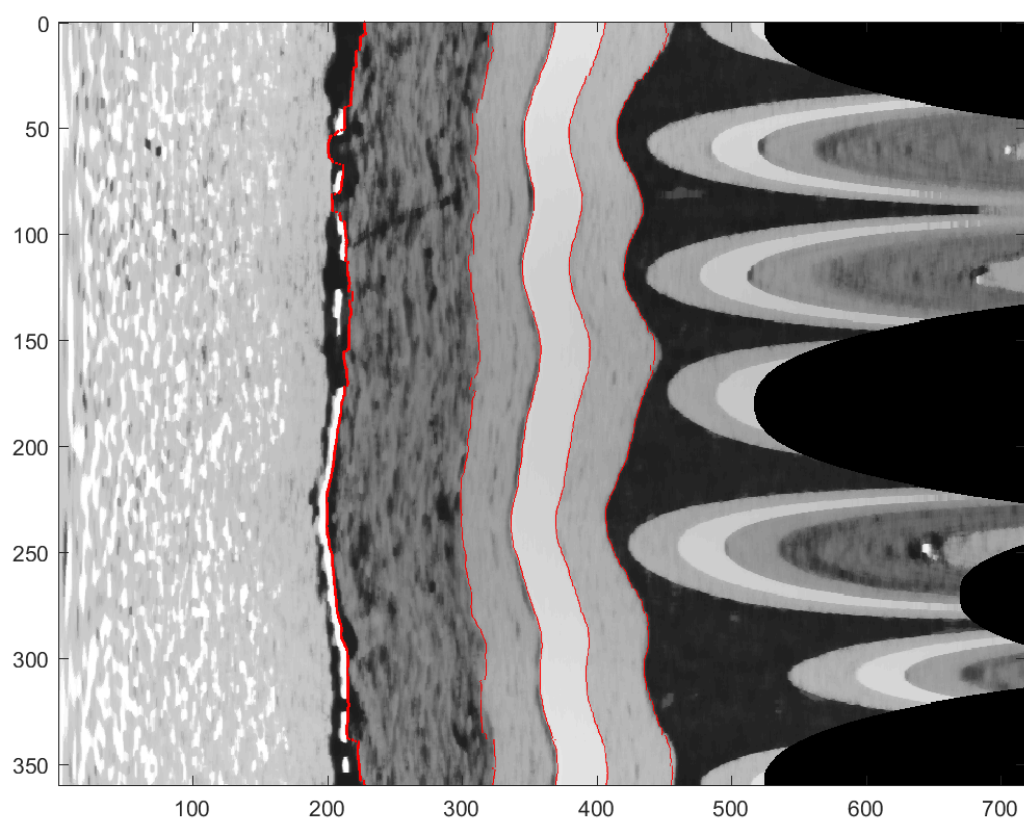
P16082301N236



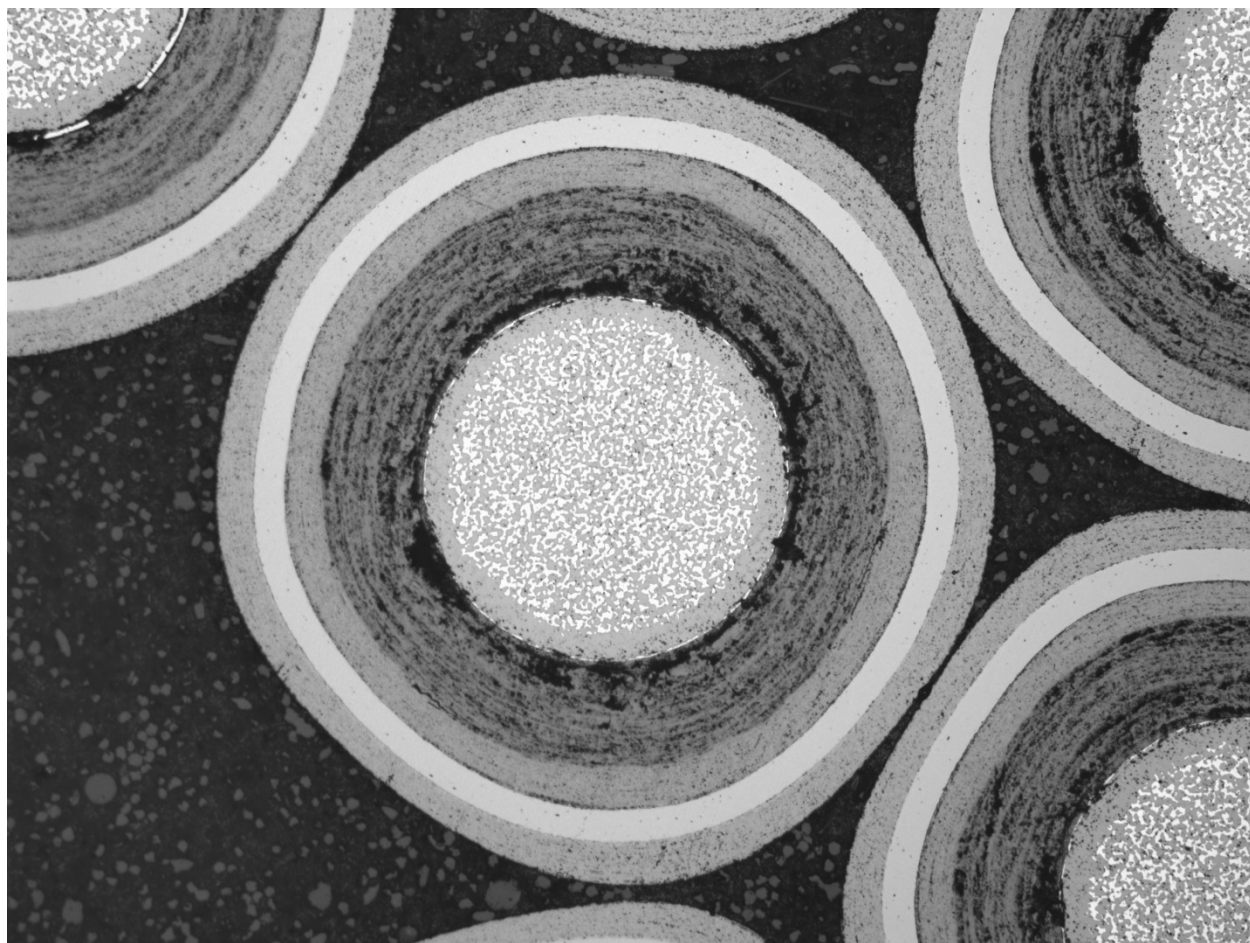
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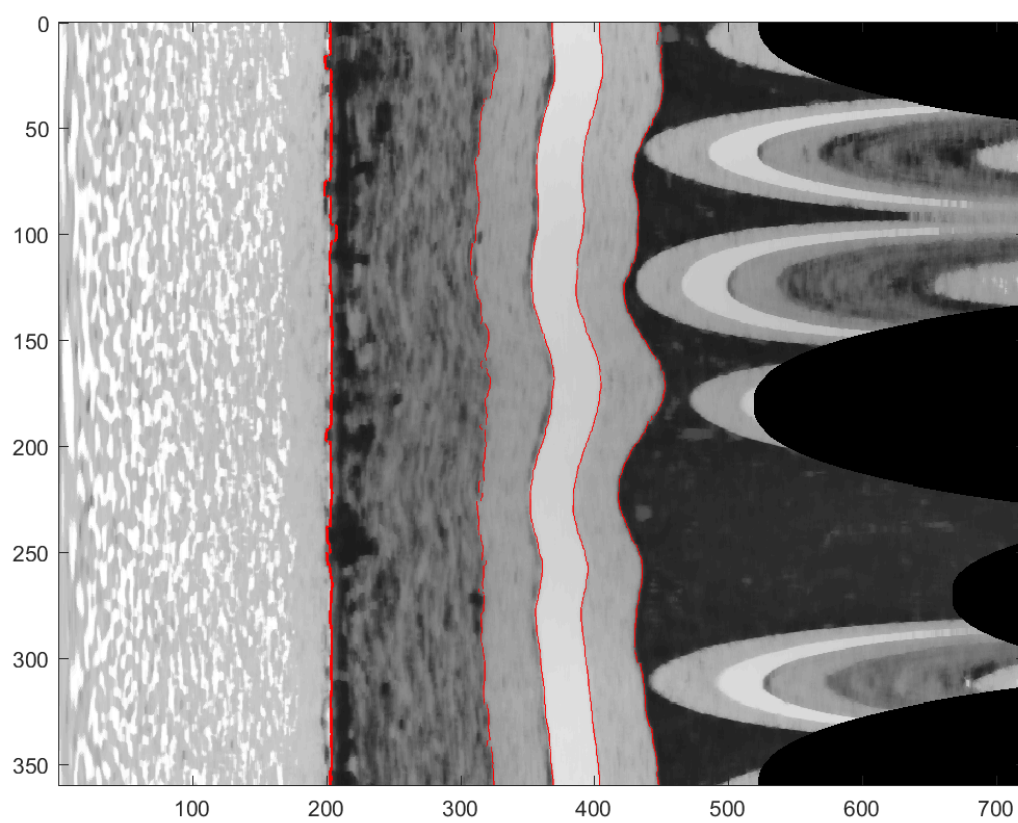
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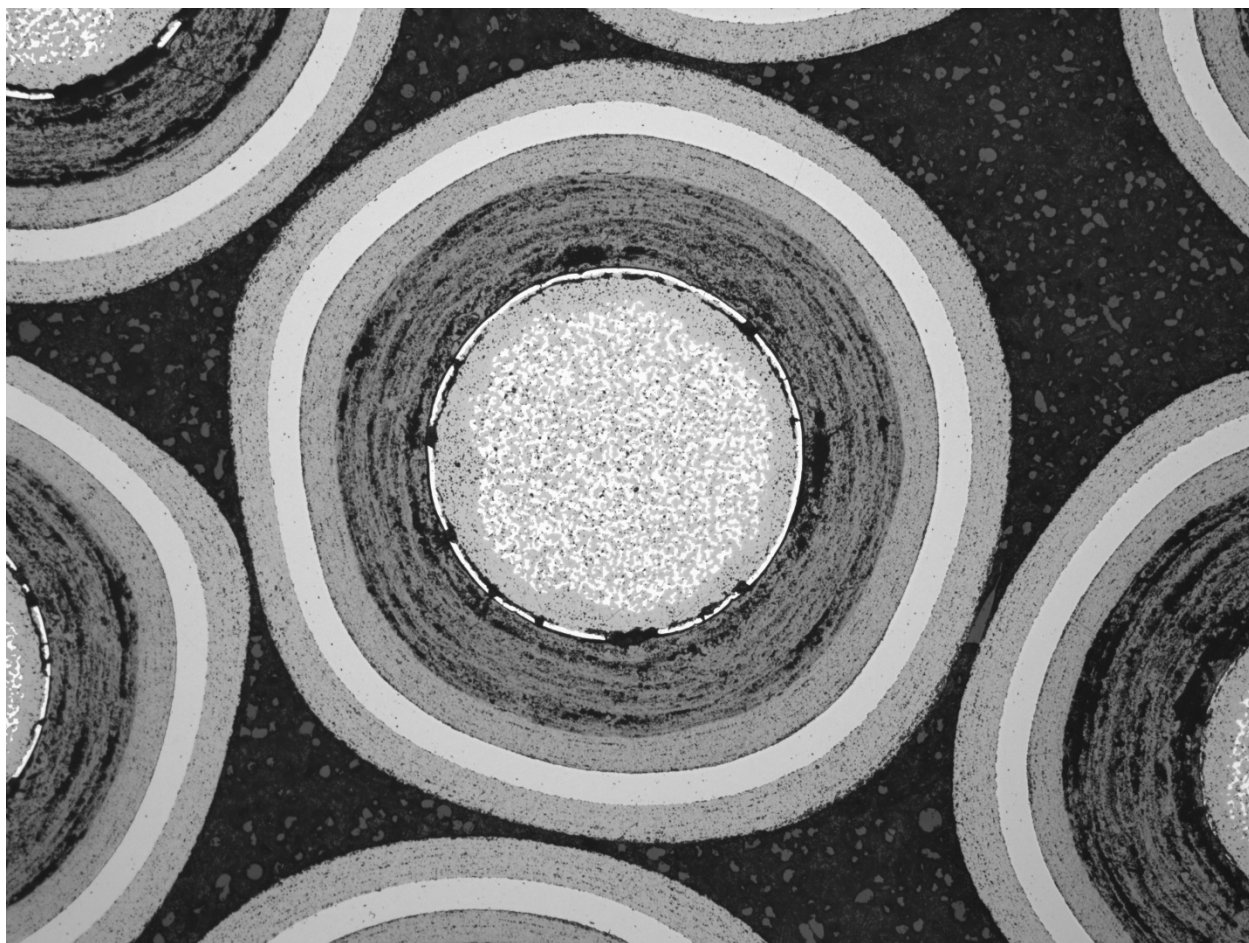


P16082301N238

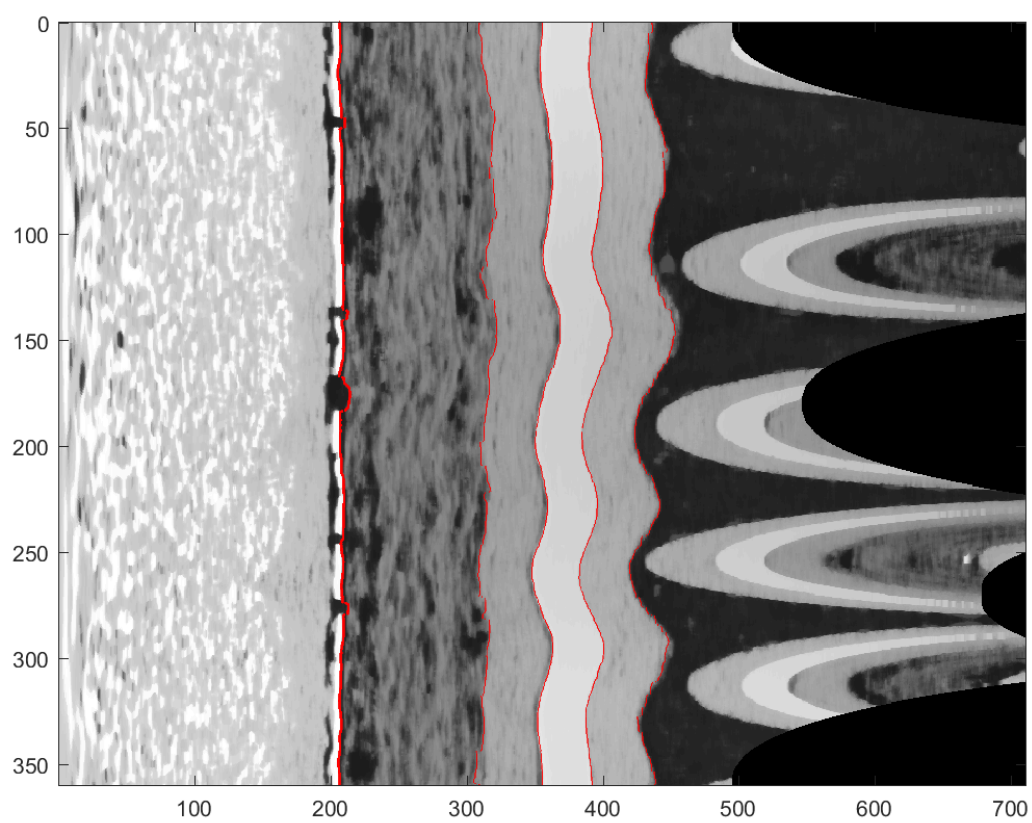


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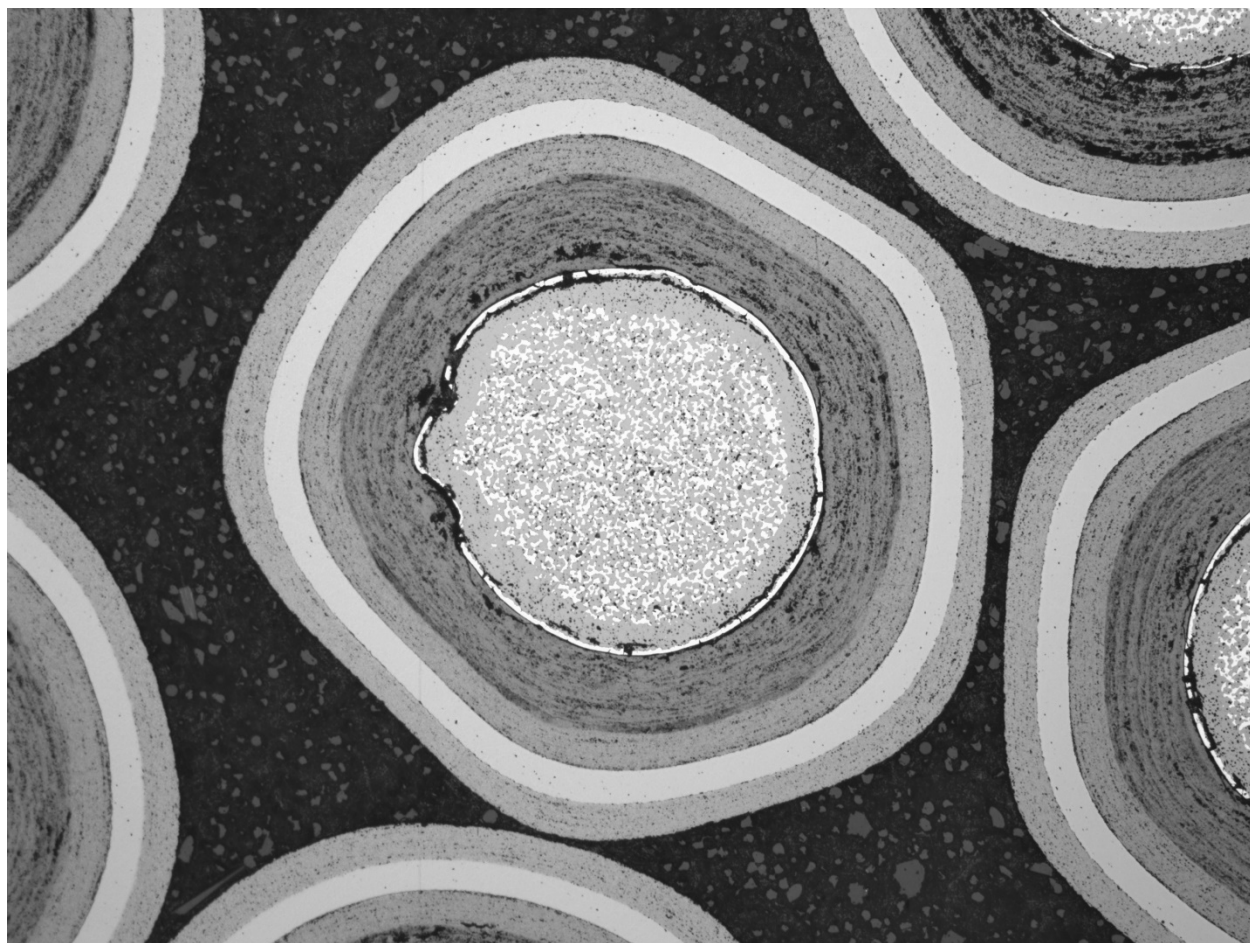




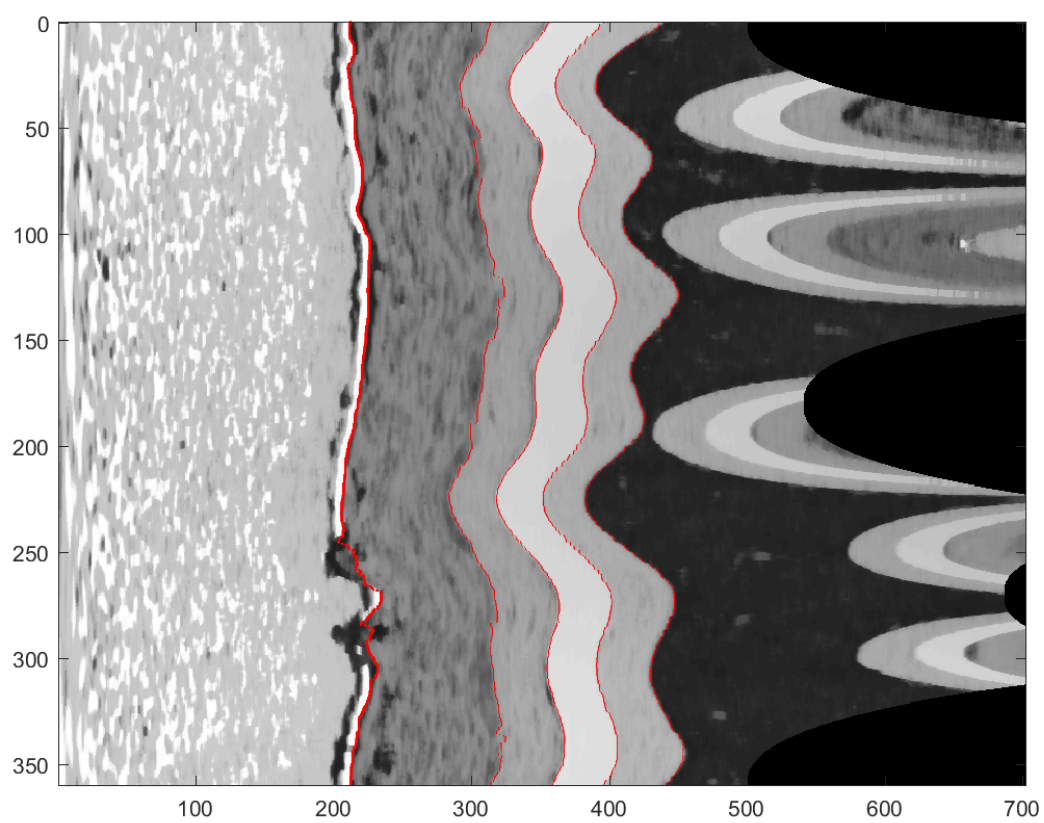
P16082301N239



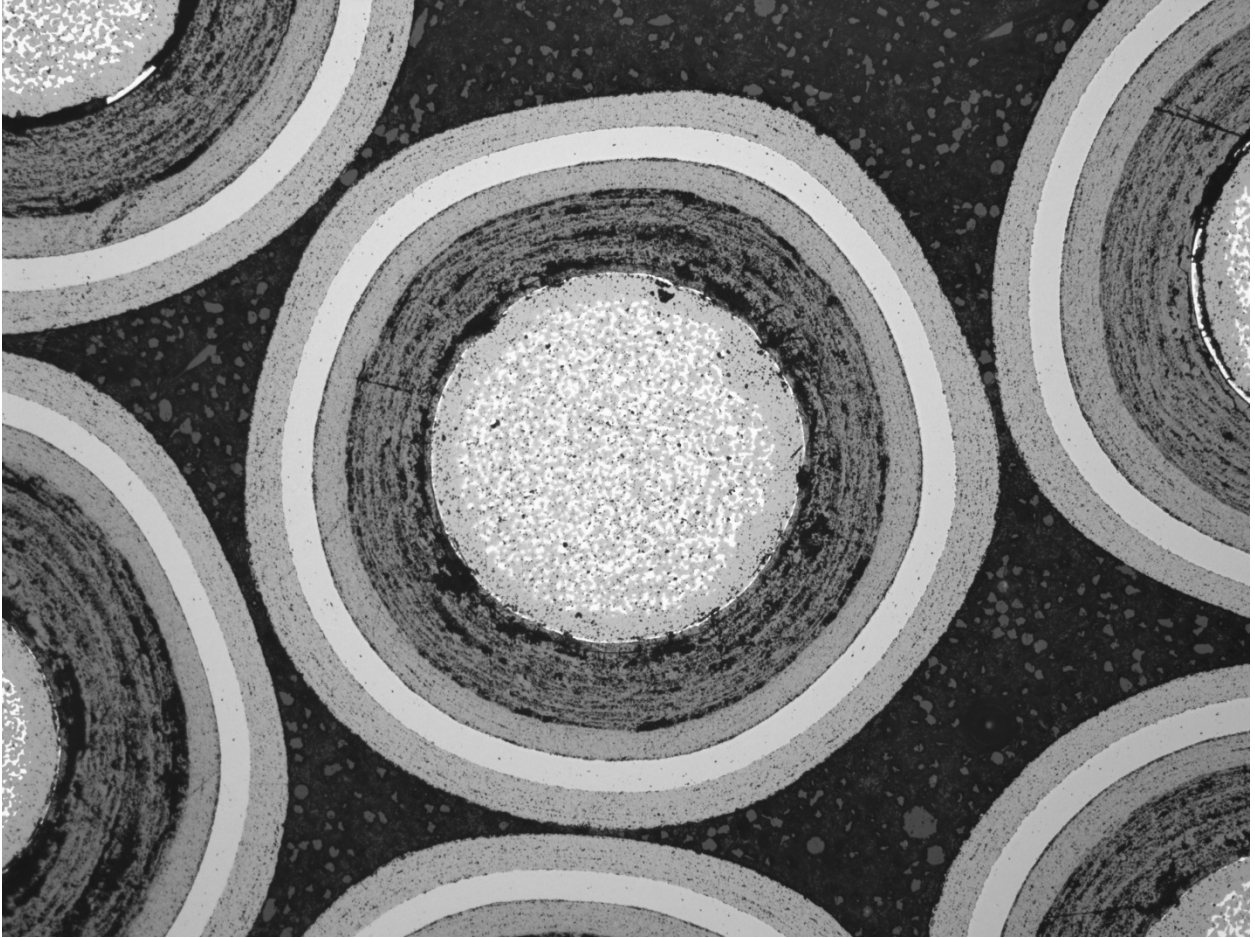
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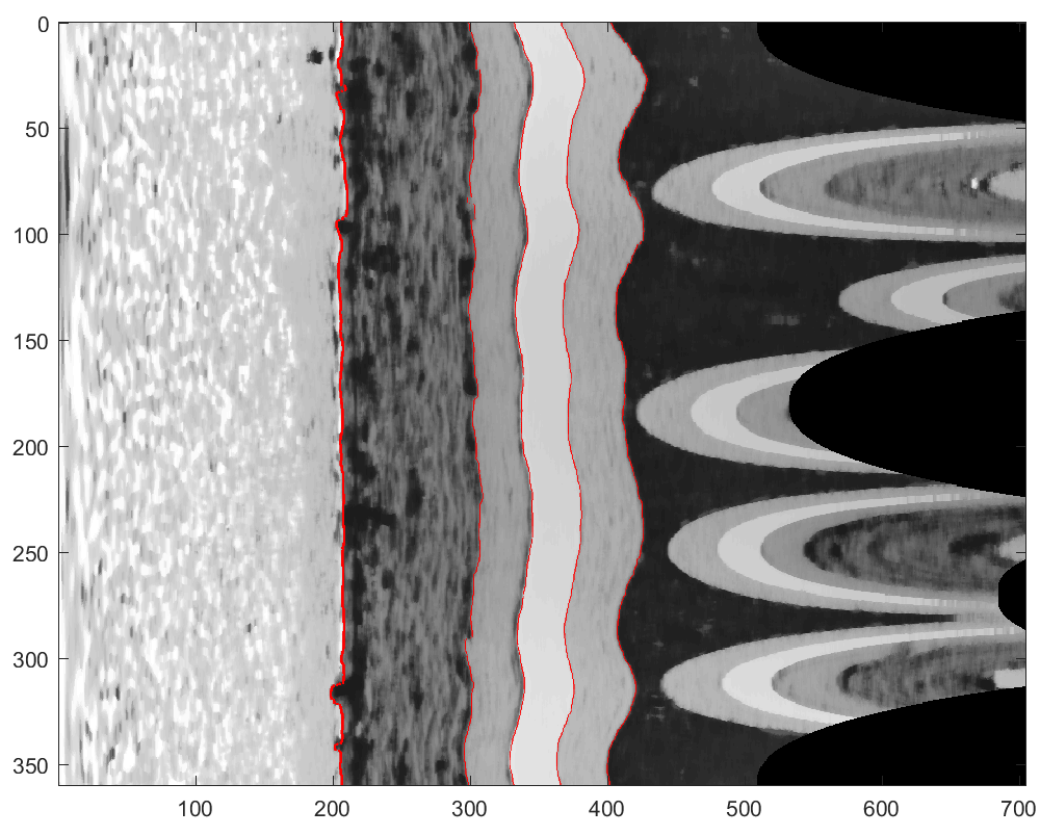
P16082301N240



**P16082301N240 unwrapped**

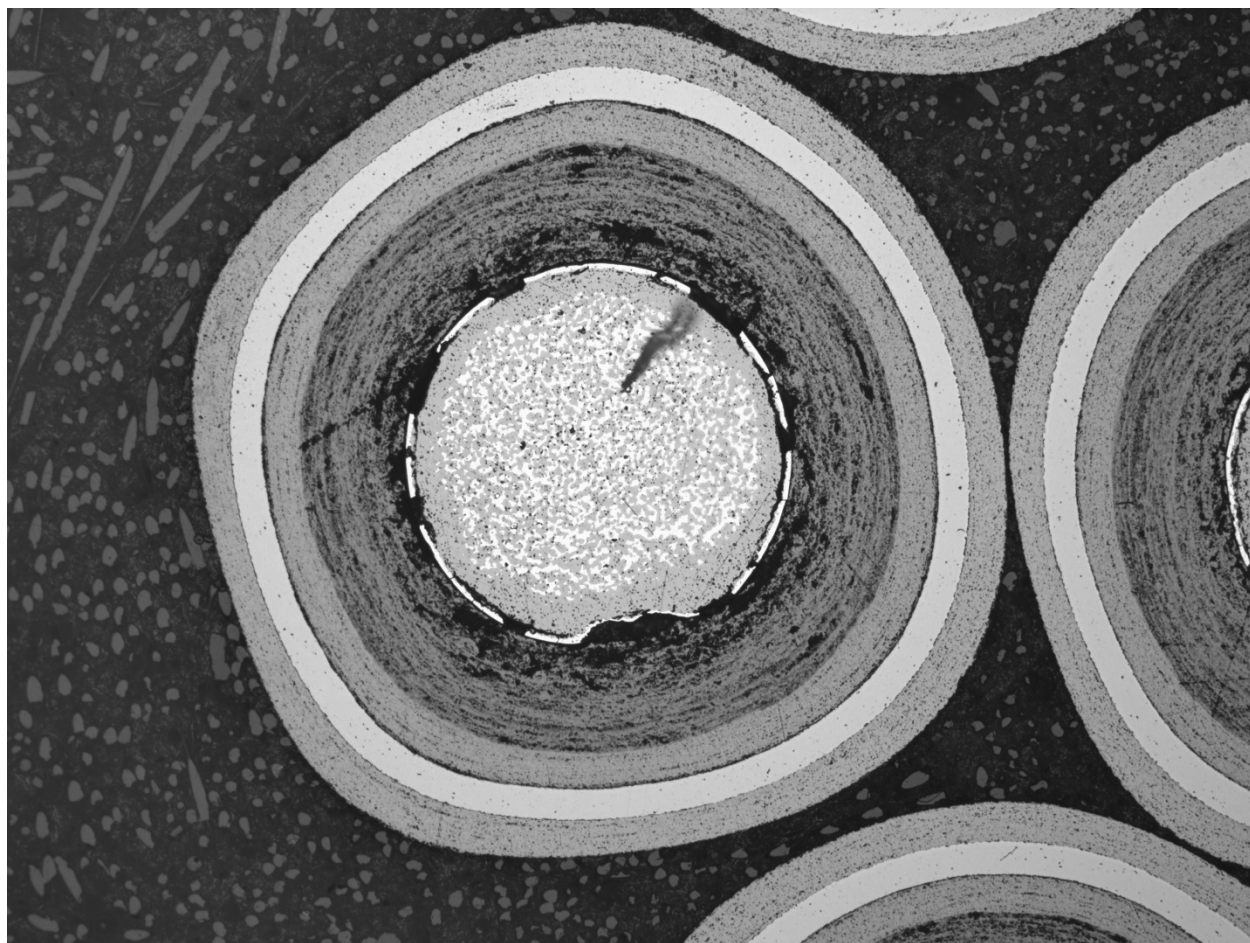


P16082301N241

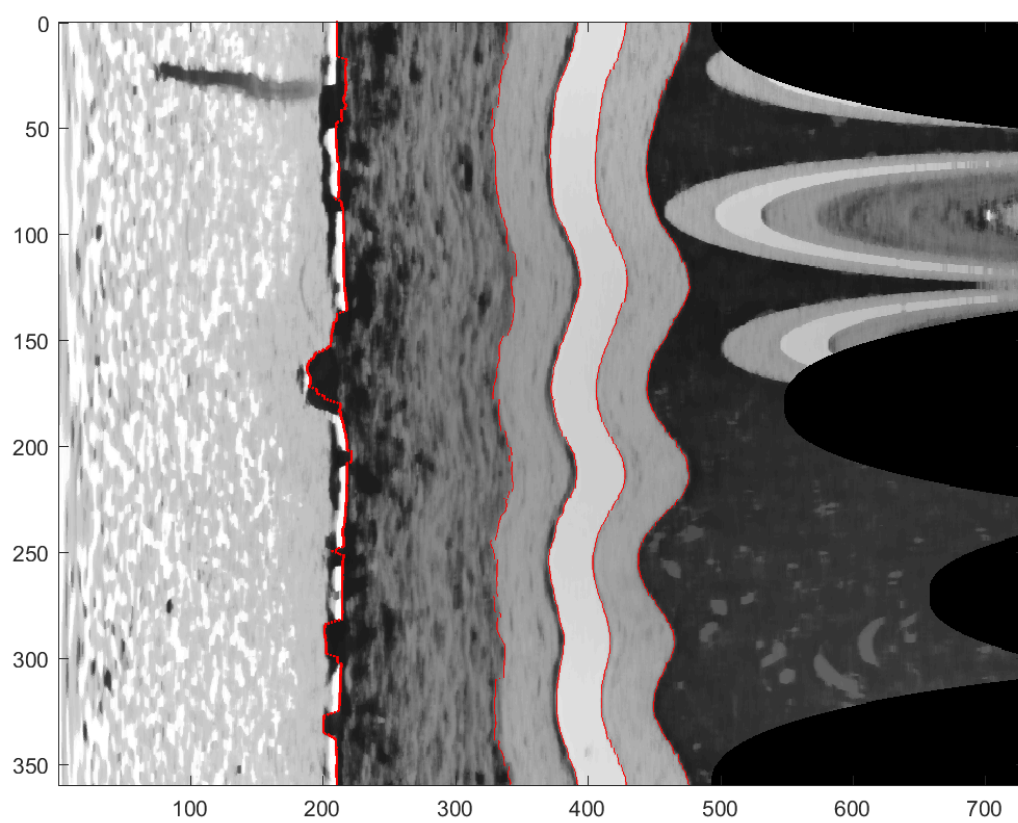


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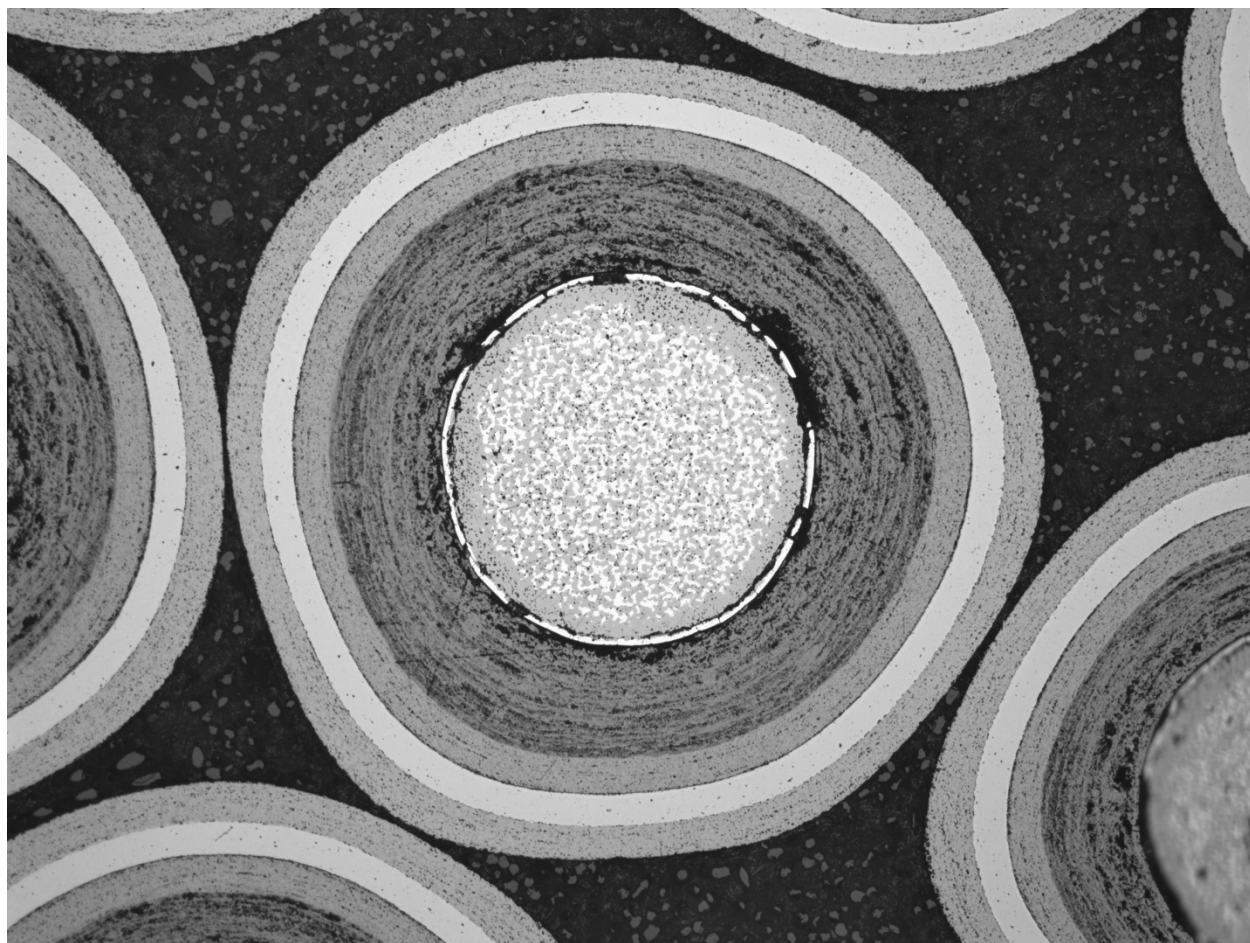




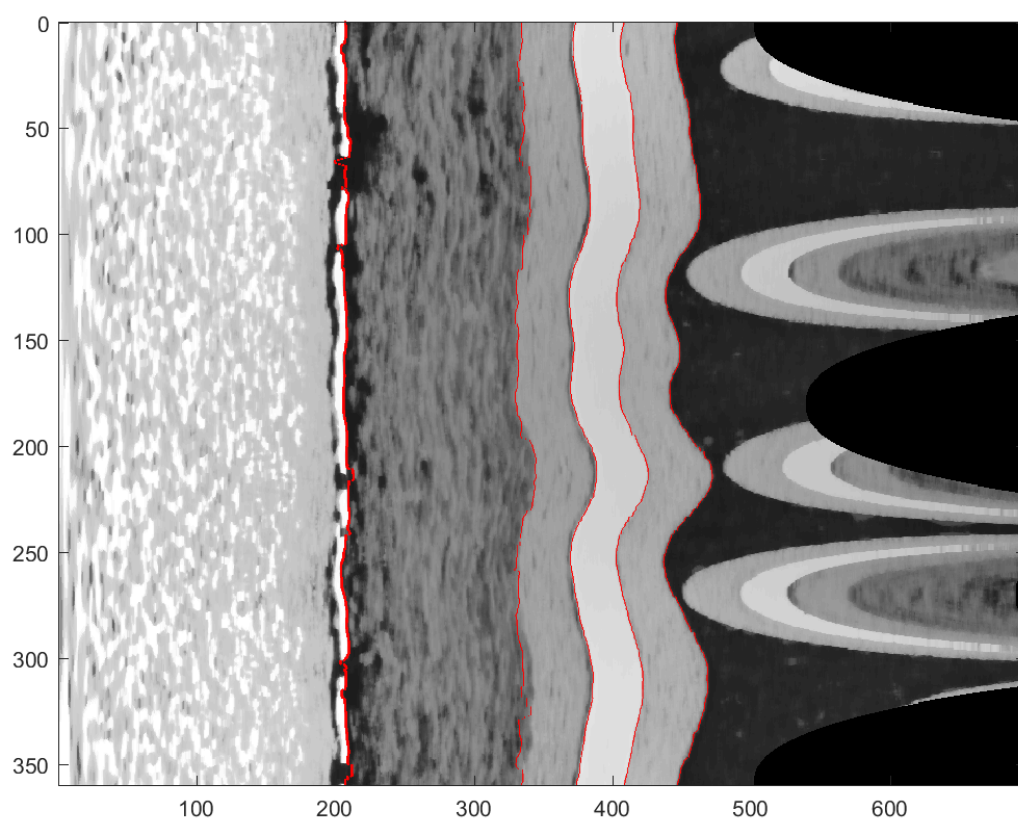
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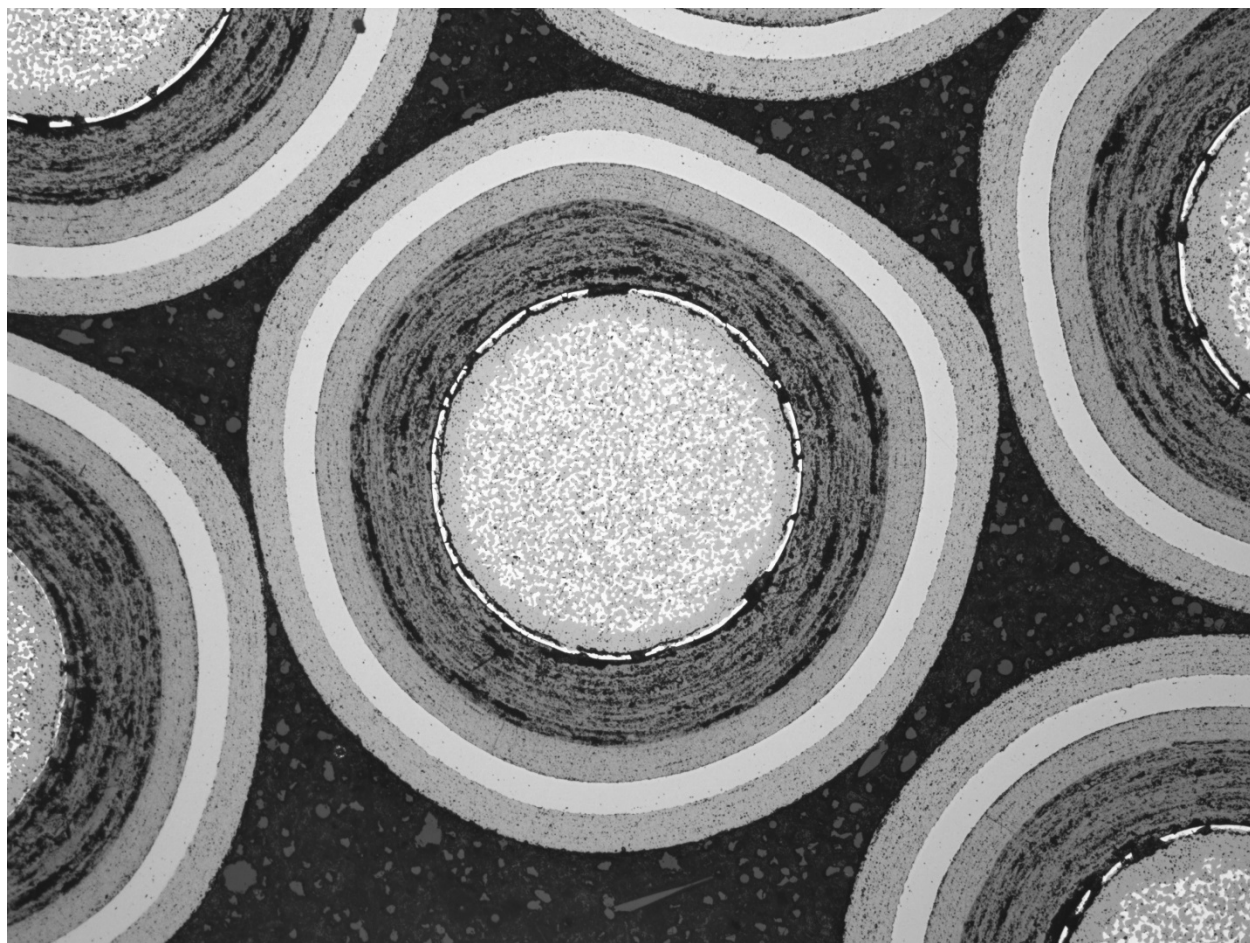
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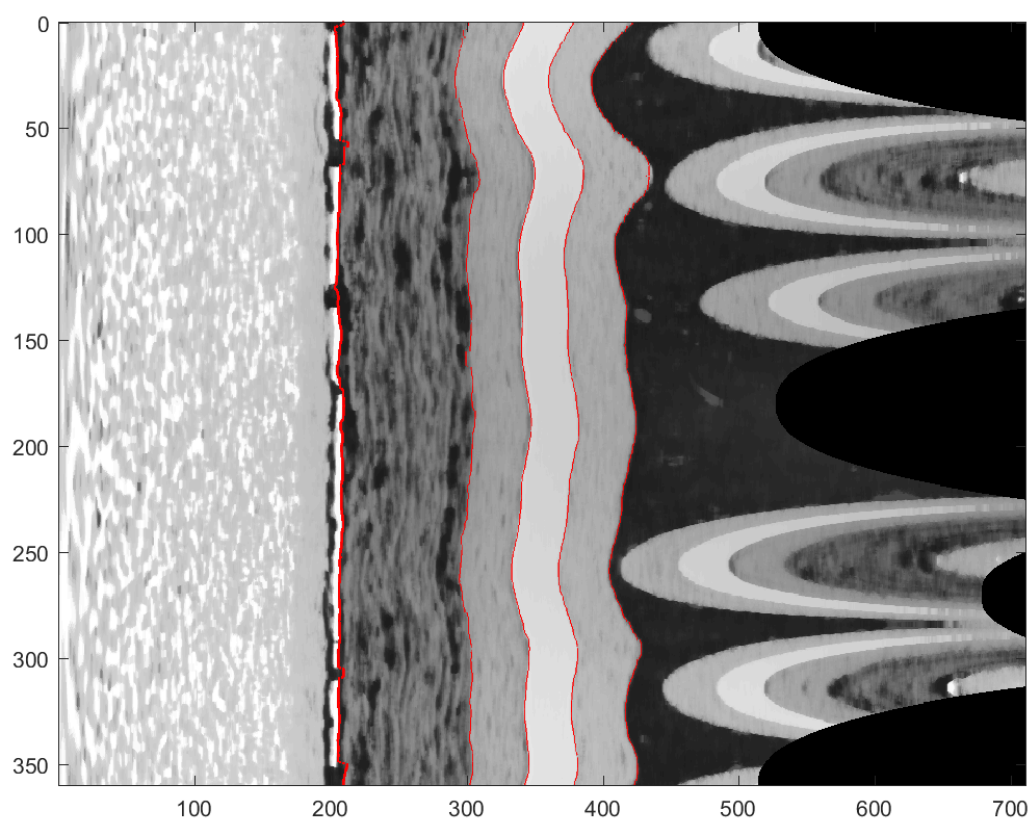
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**P16082301N243 unwrapped**

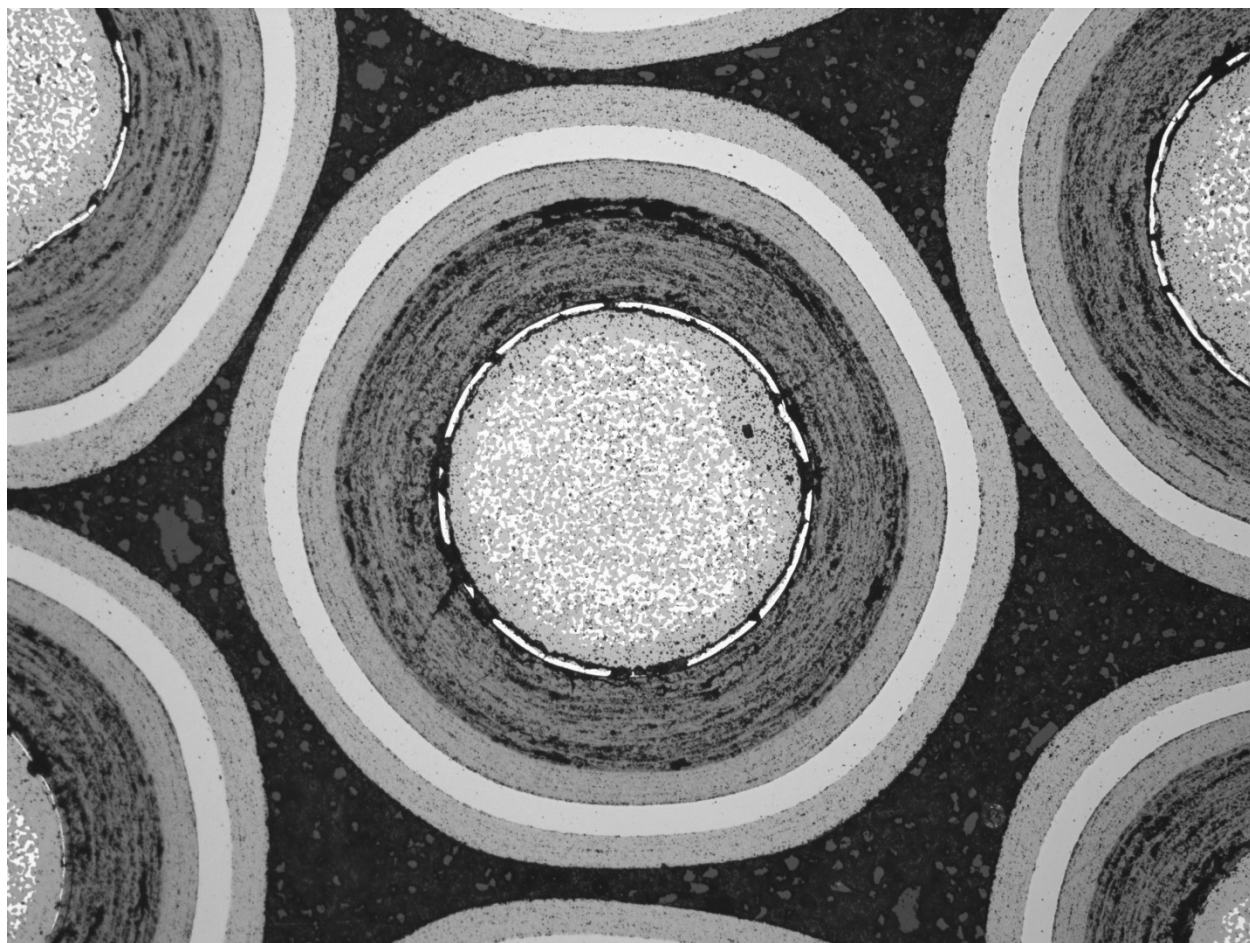


P16082301N244

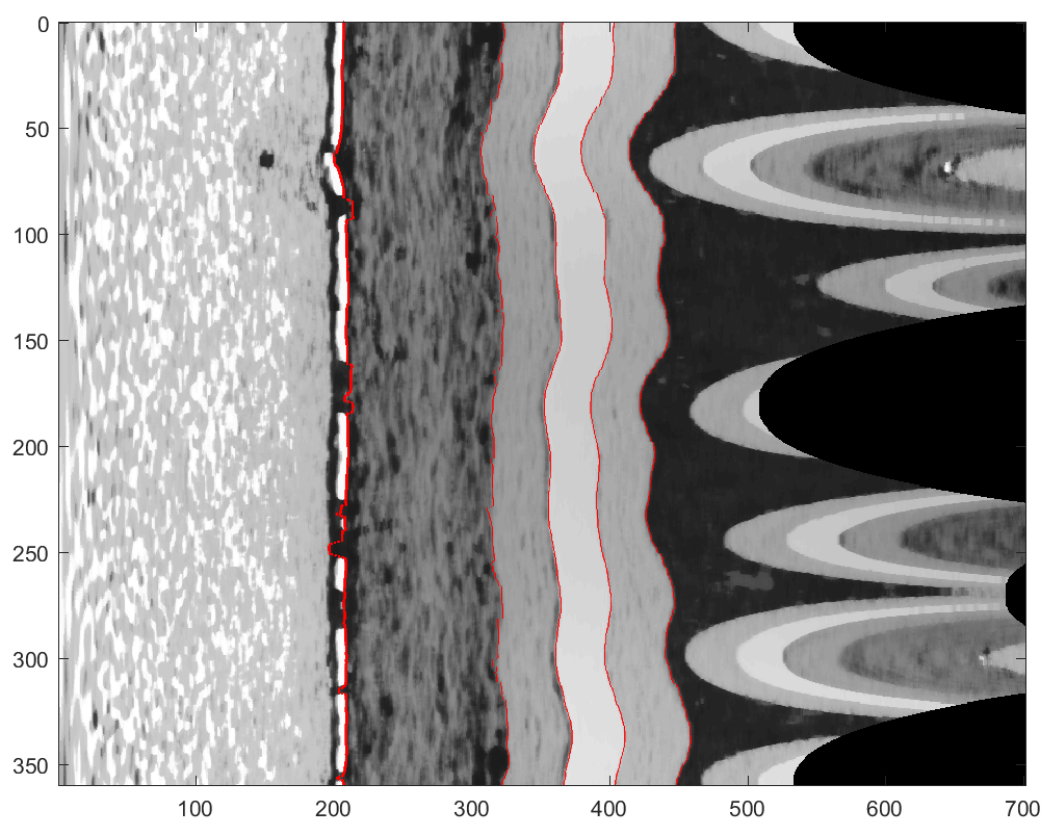


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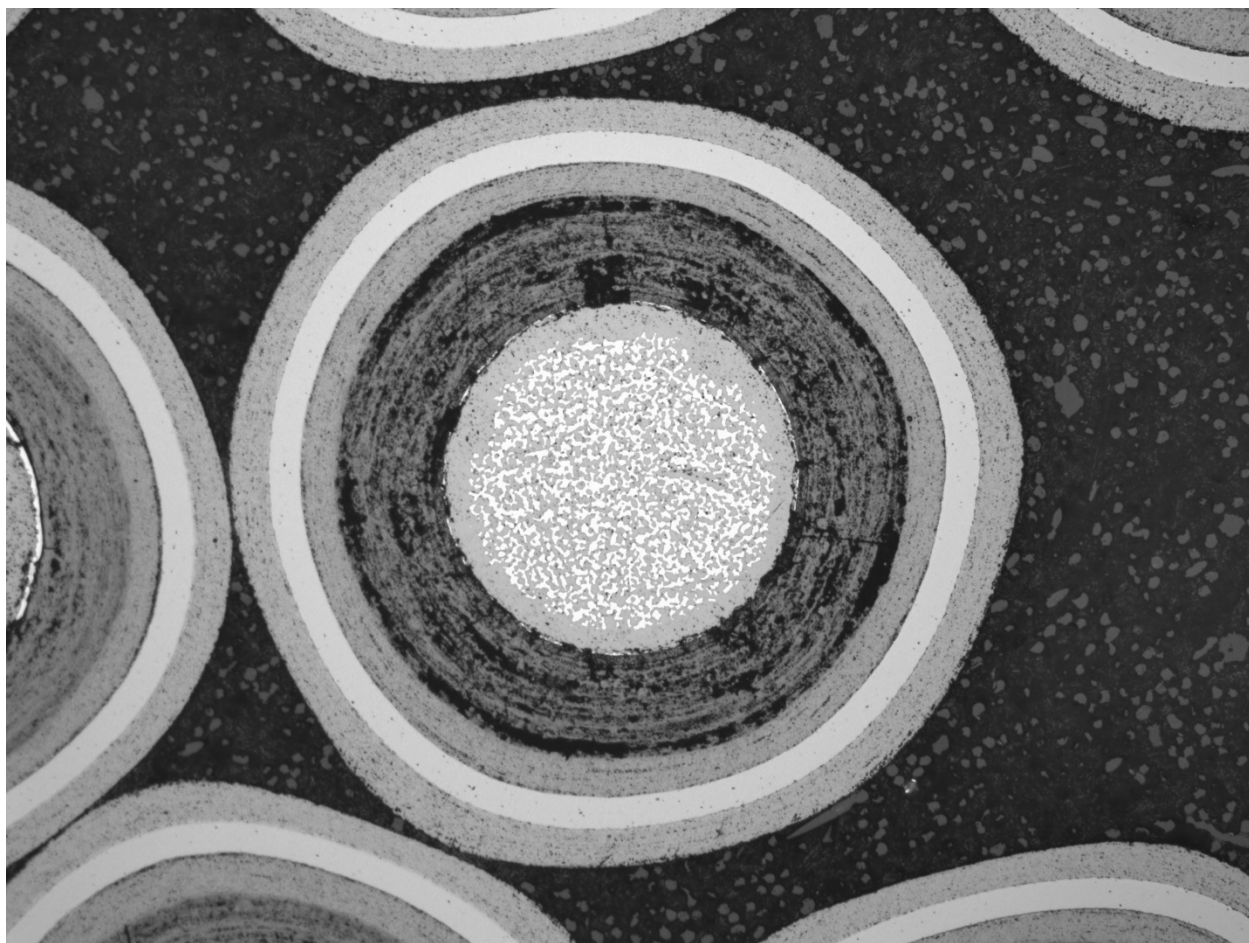




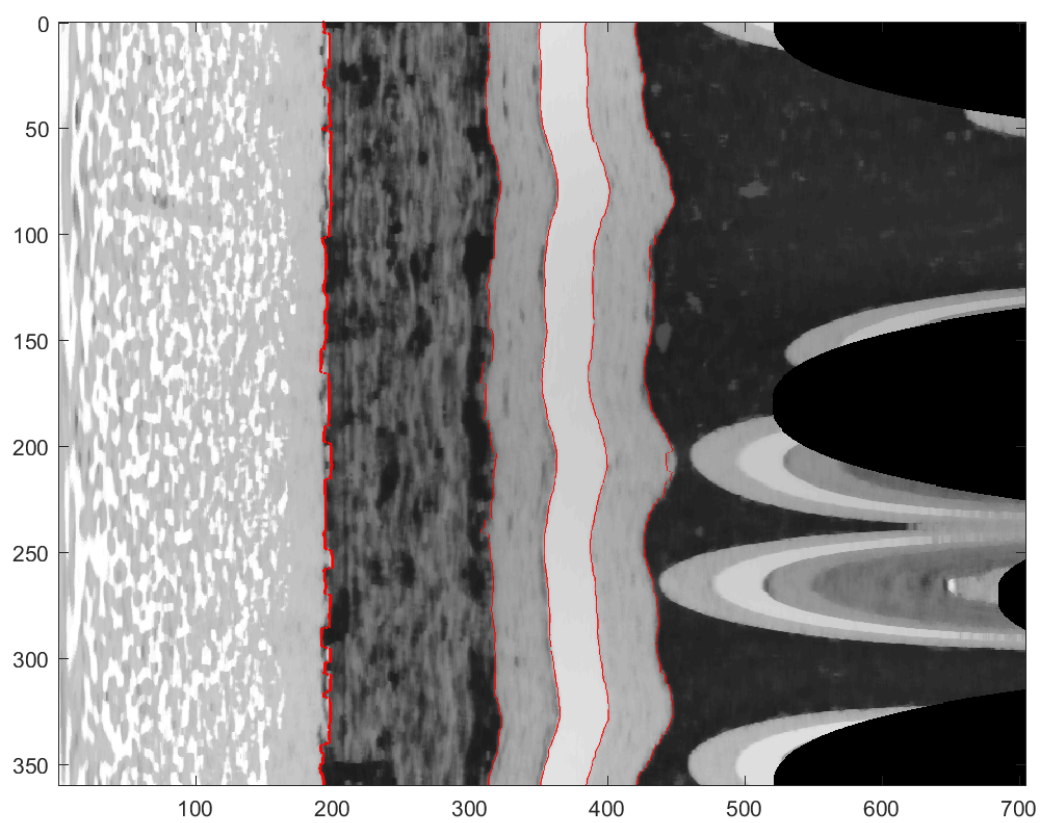
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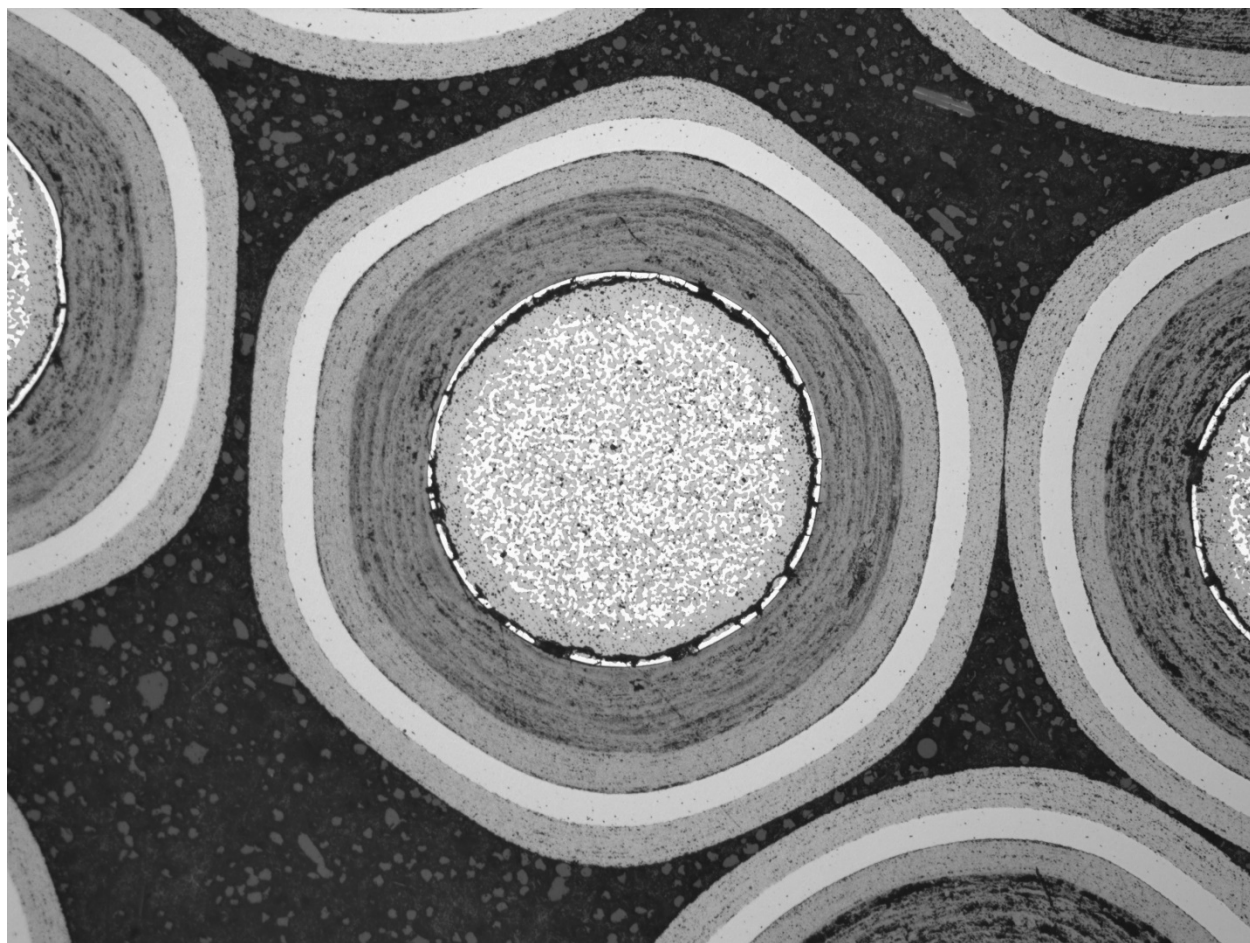
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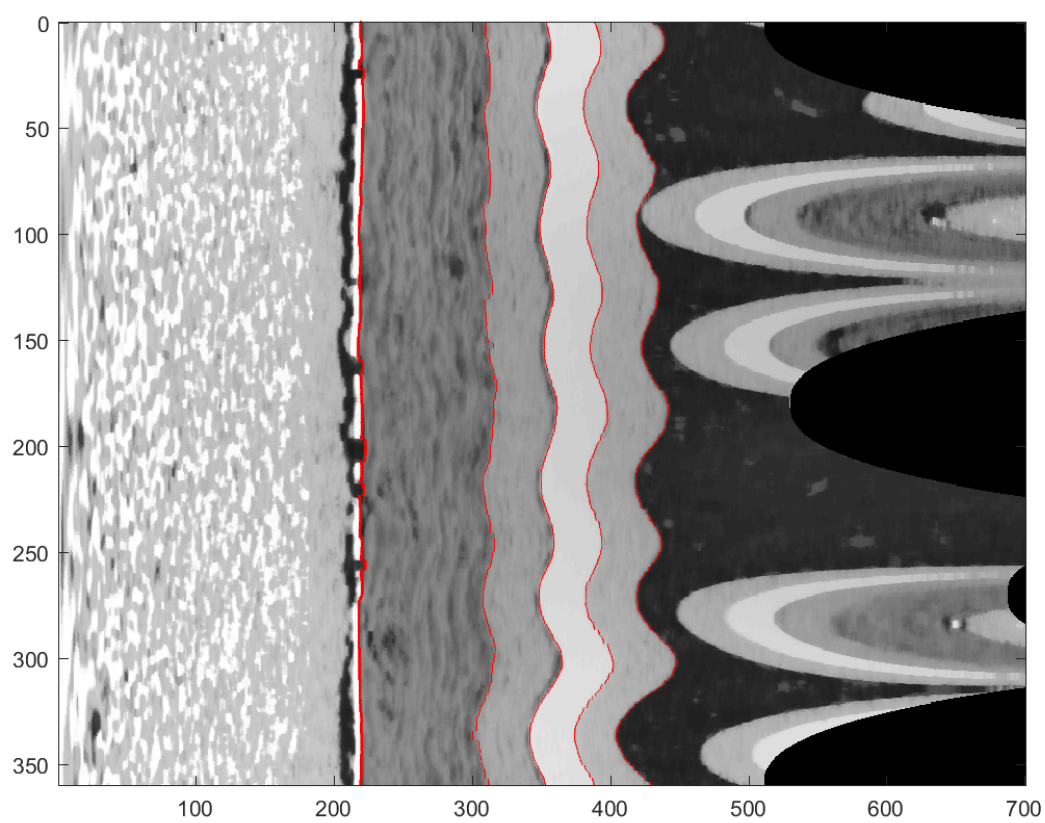
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**P16082301N246 unwrapped**

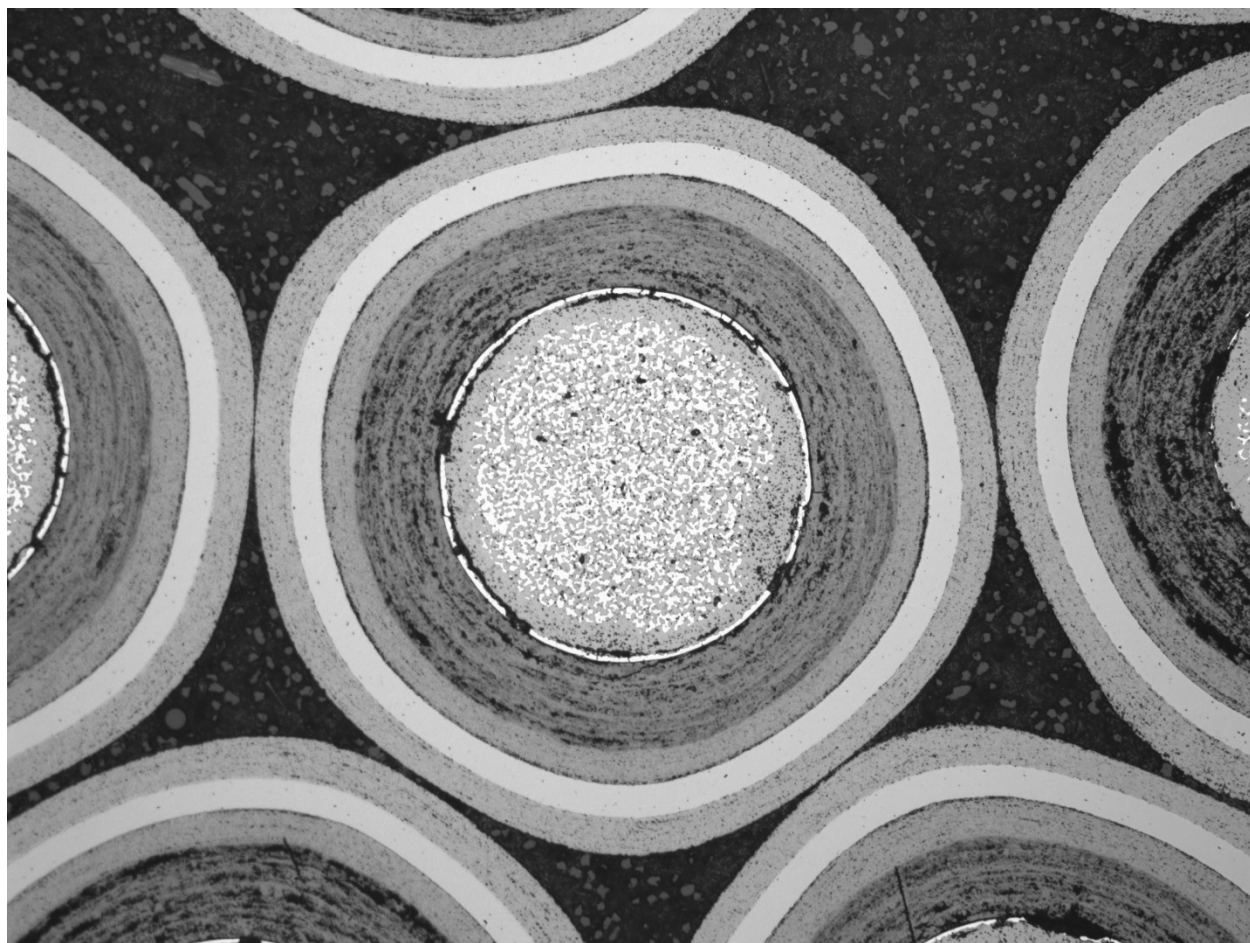


P16082301N247

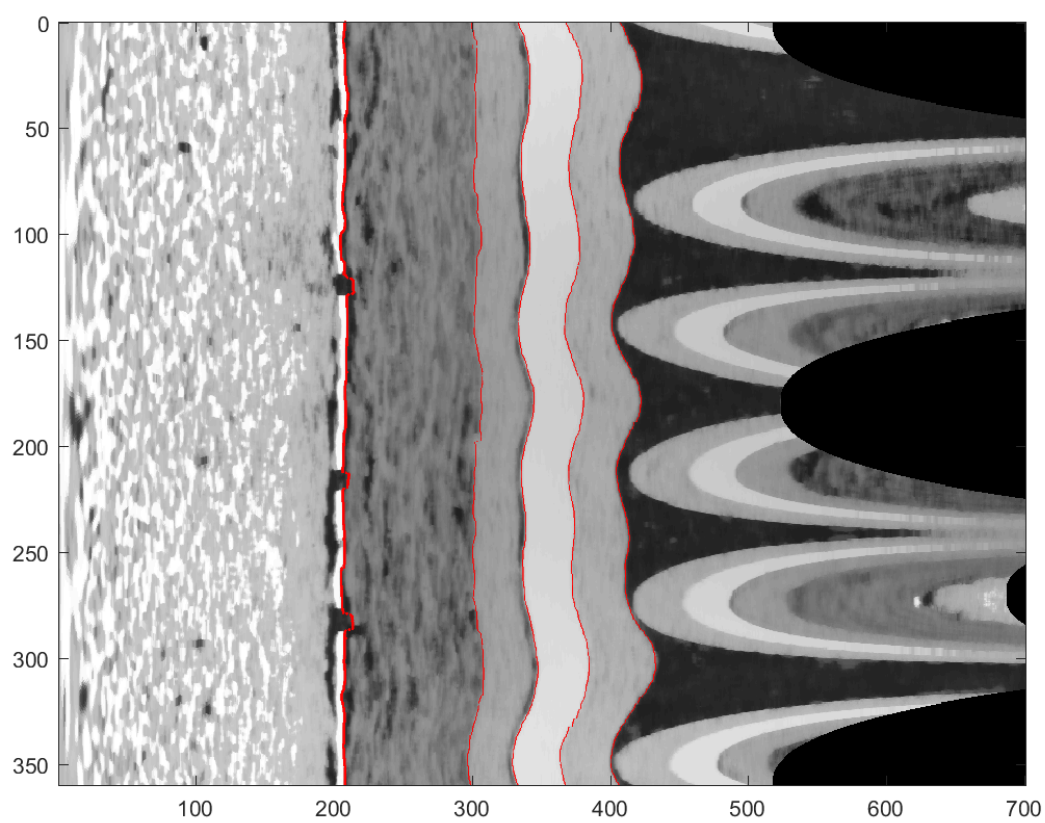


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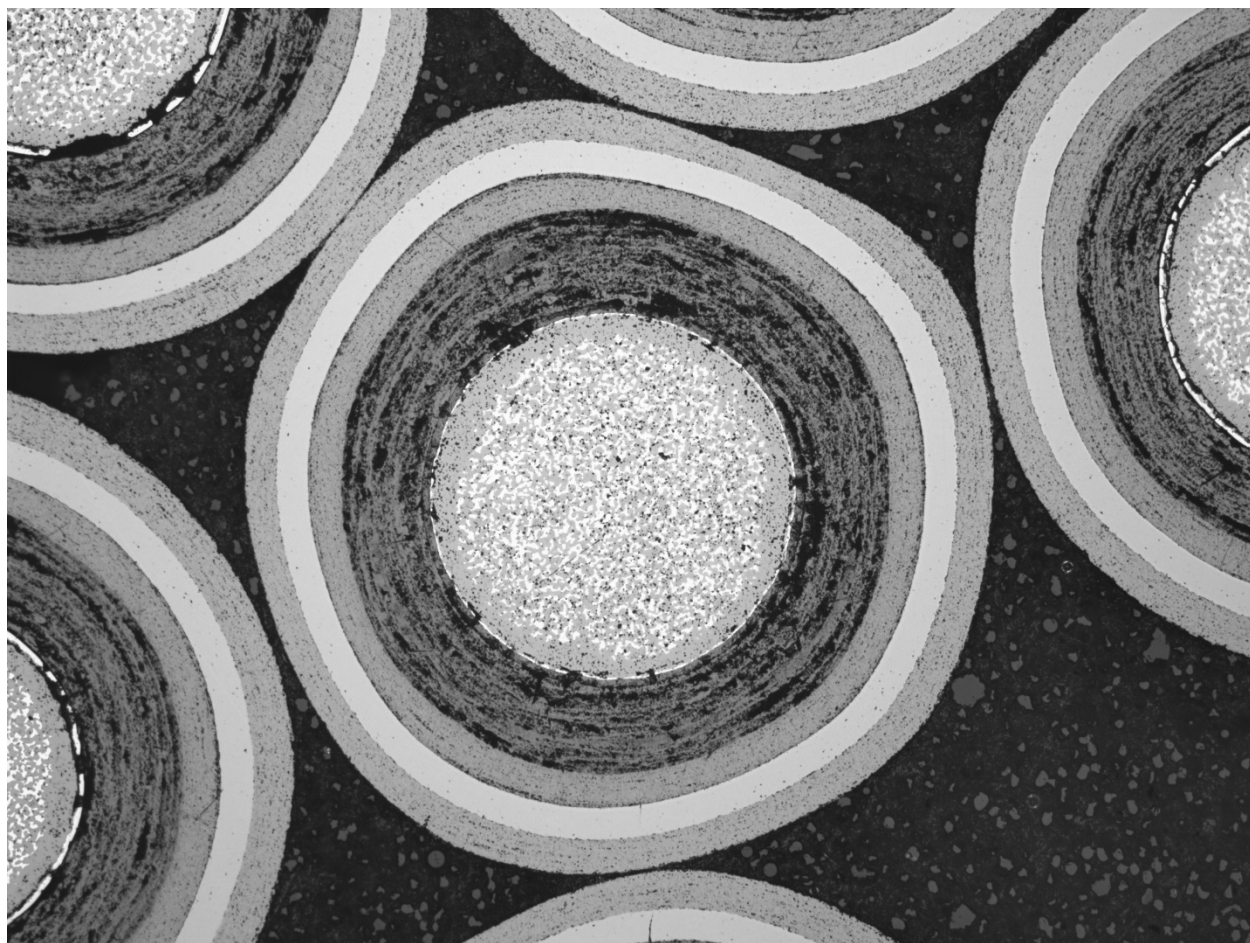




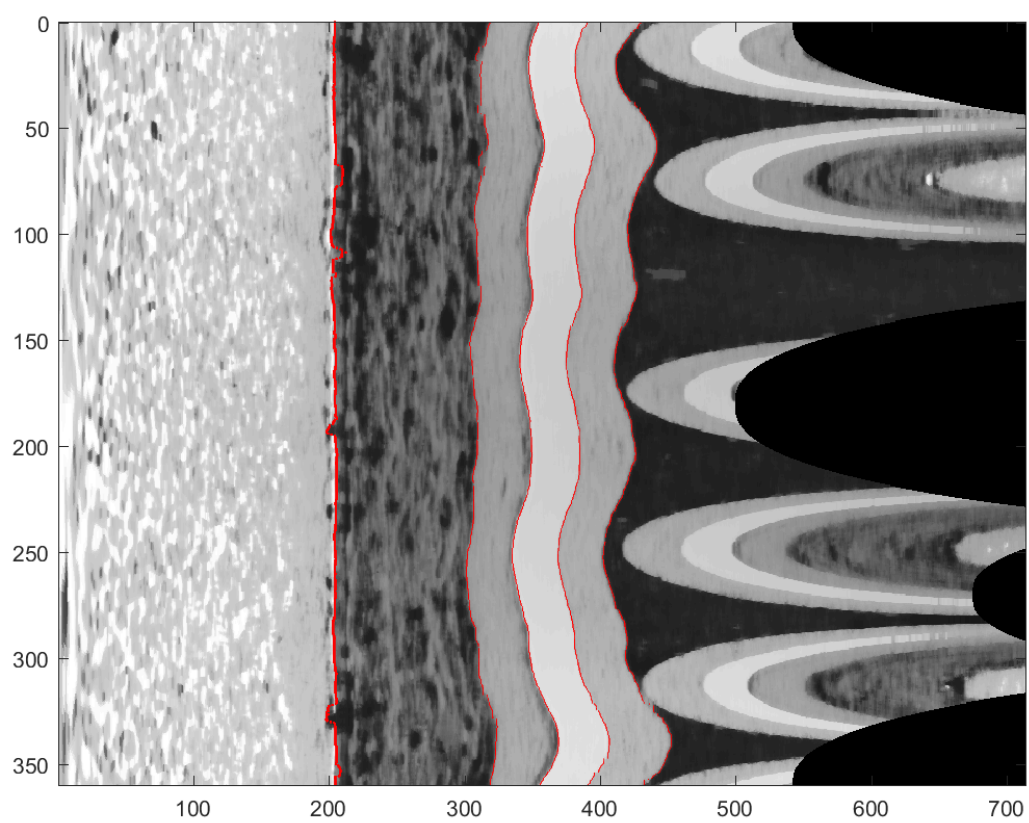
P16082301N248



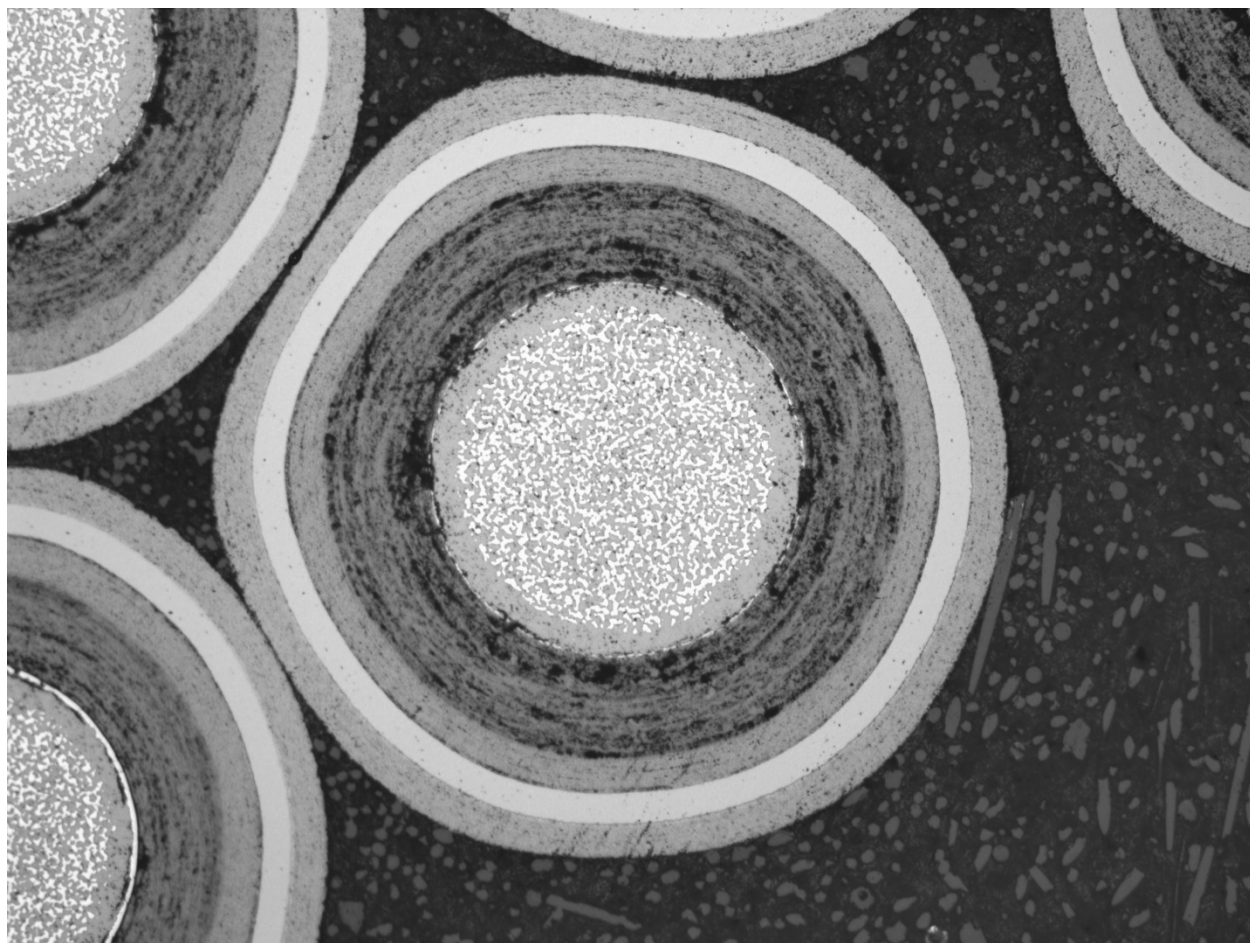
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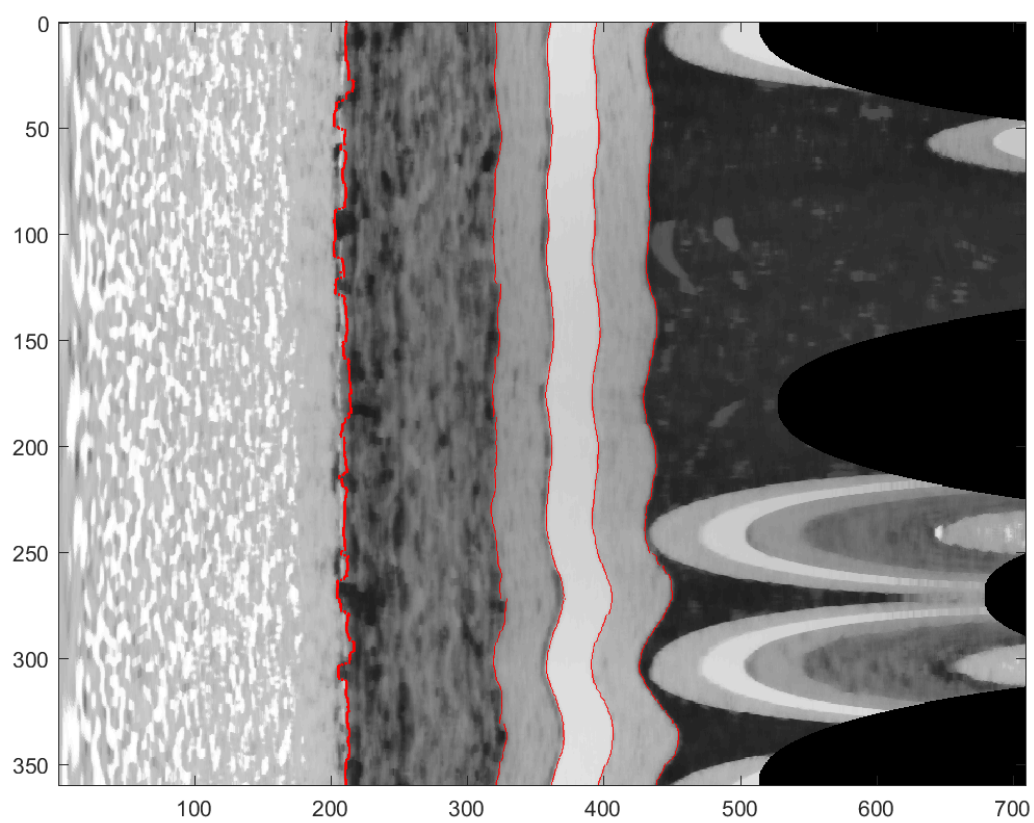
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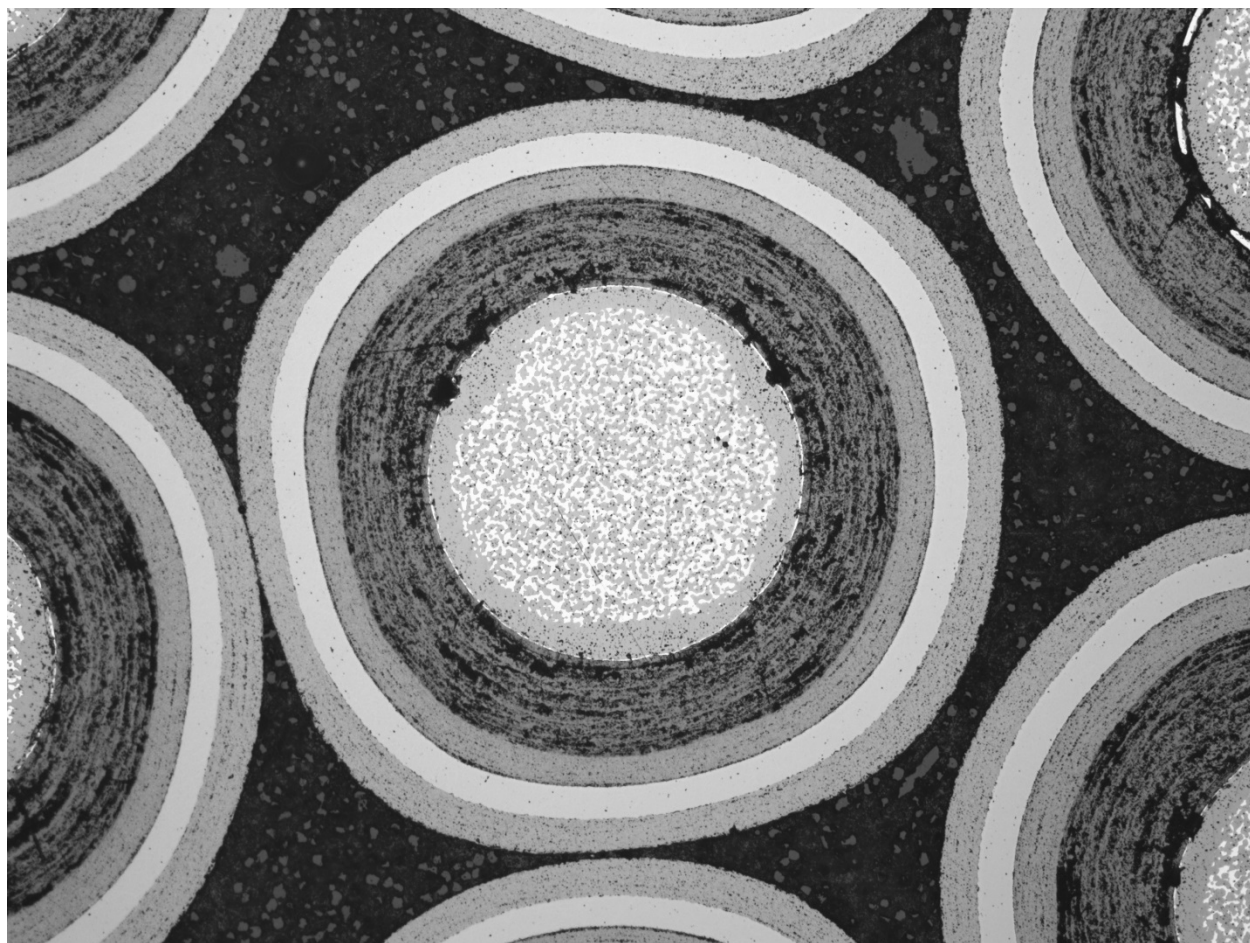


P16082301N253

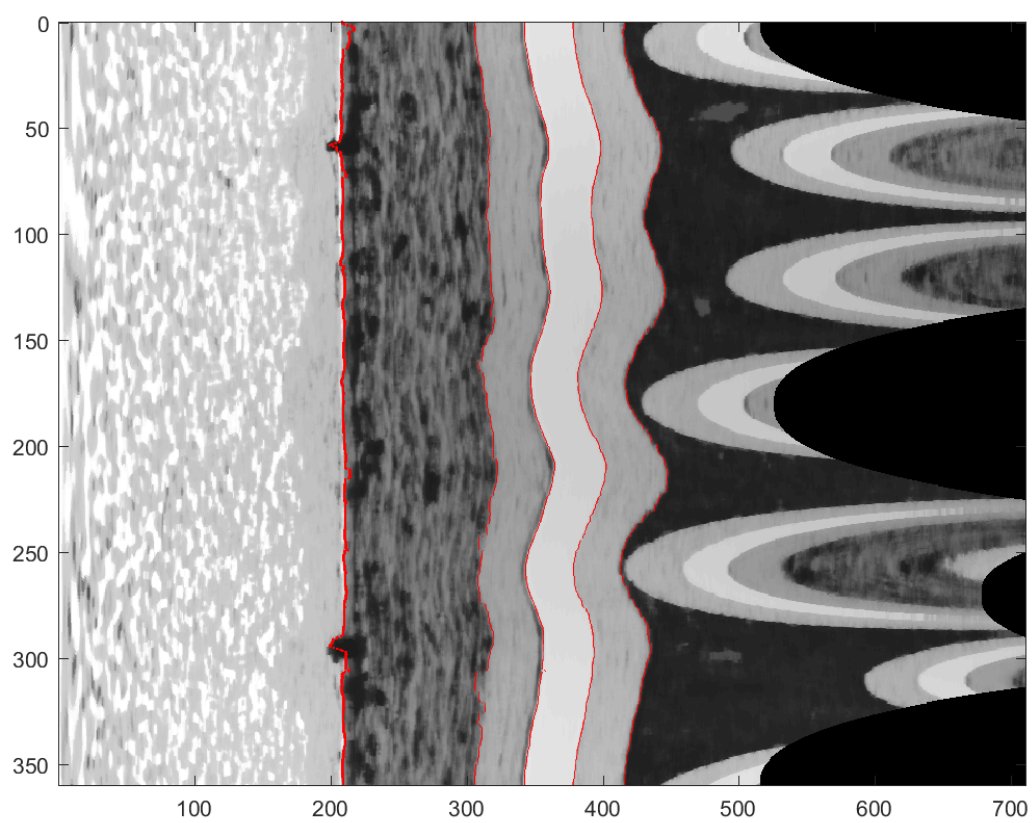


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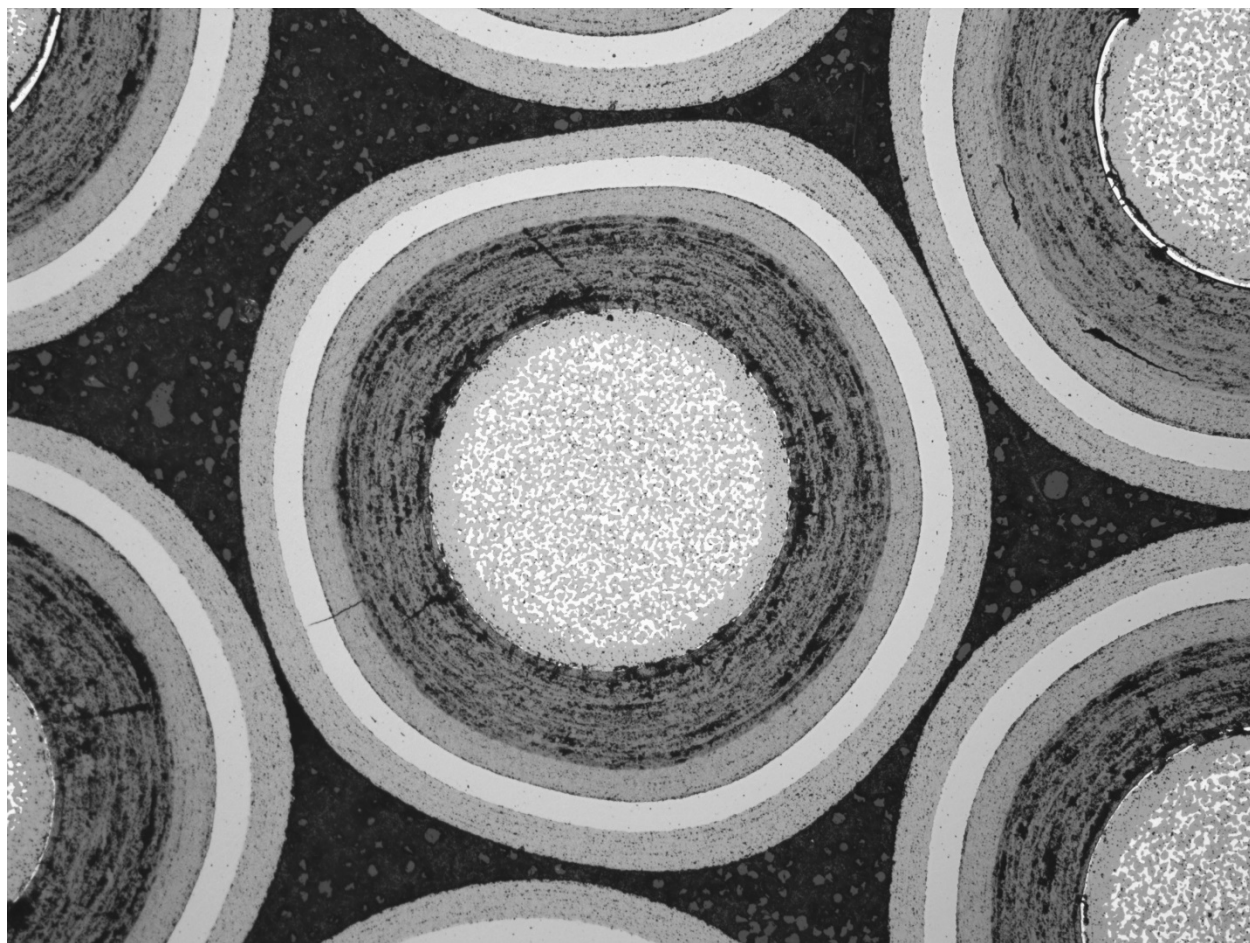




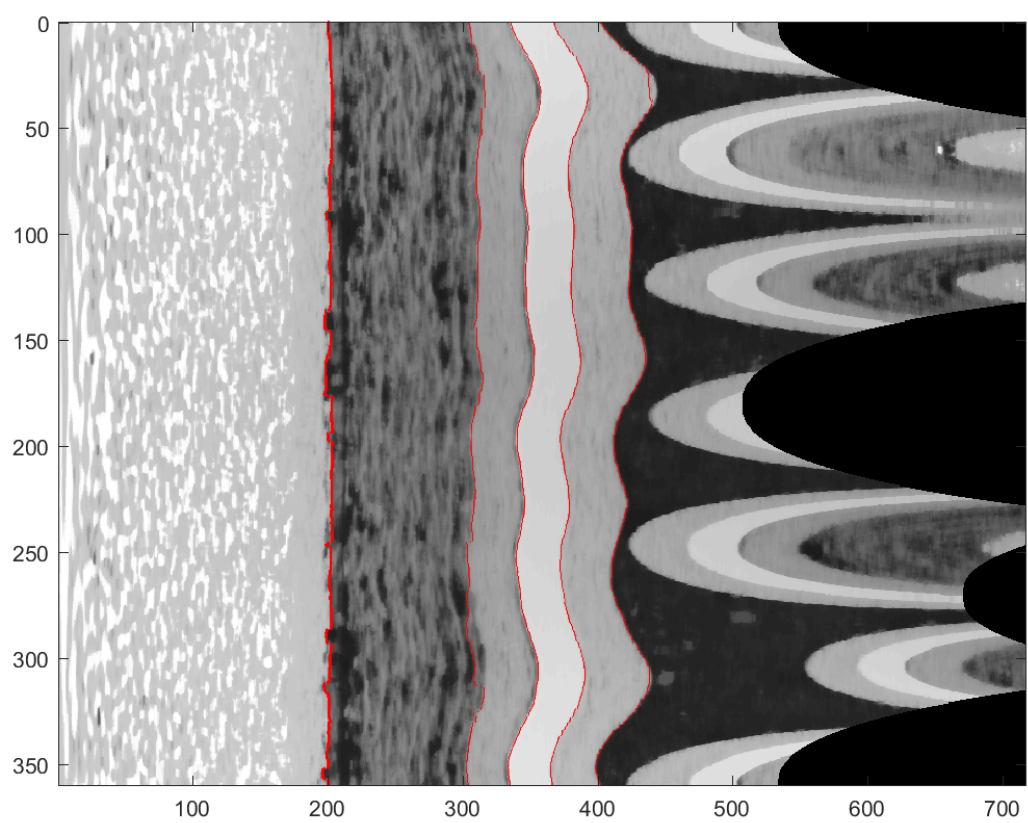
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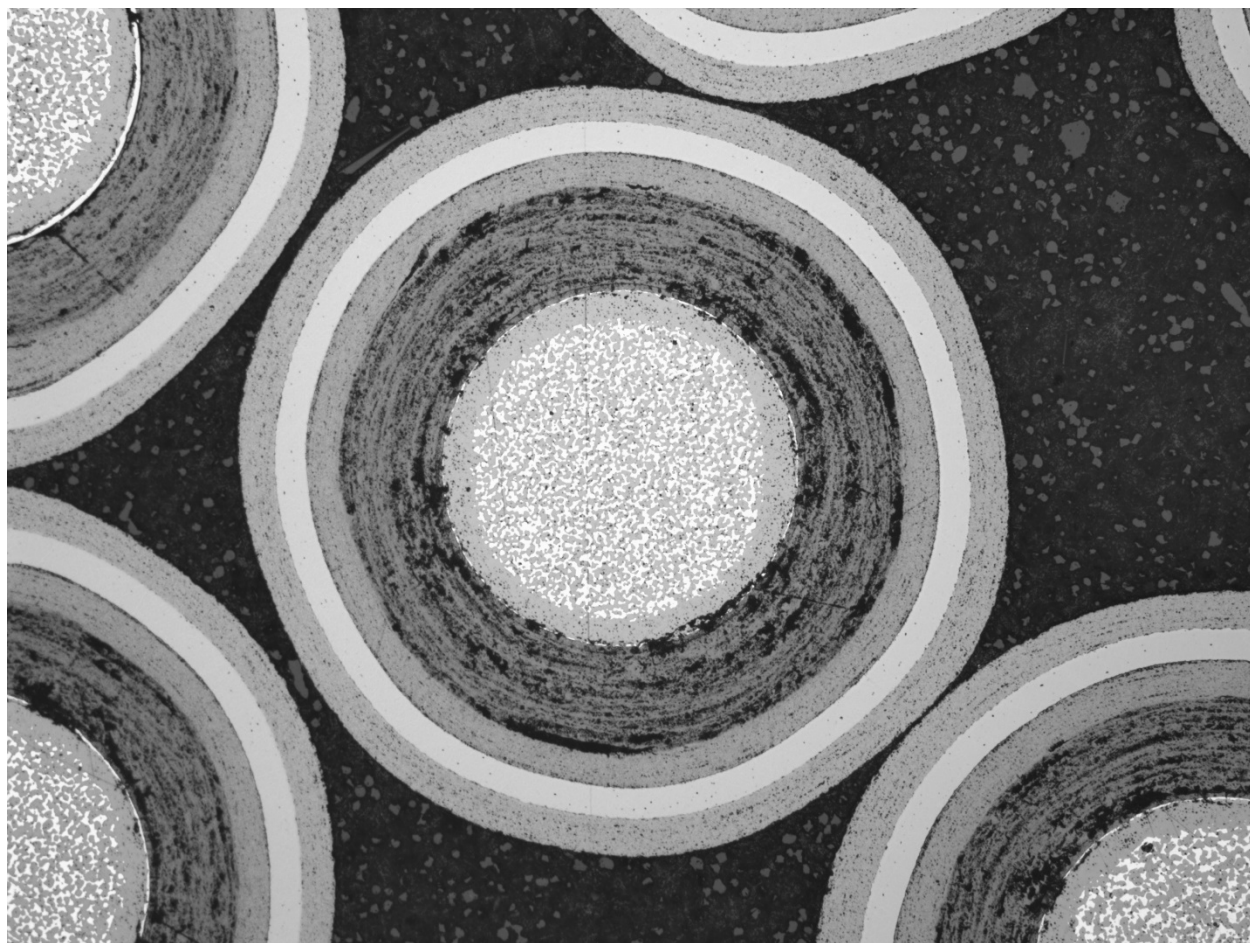
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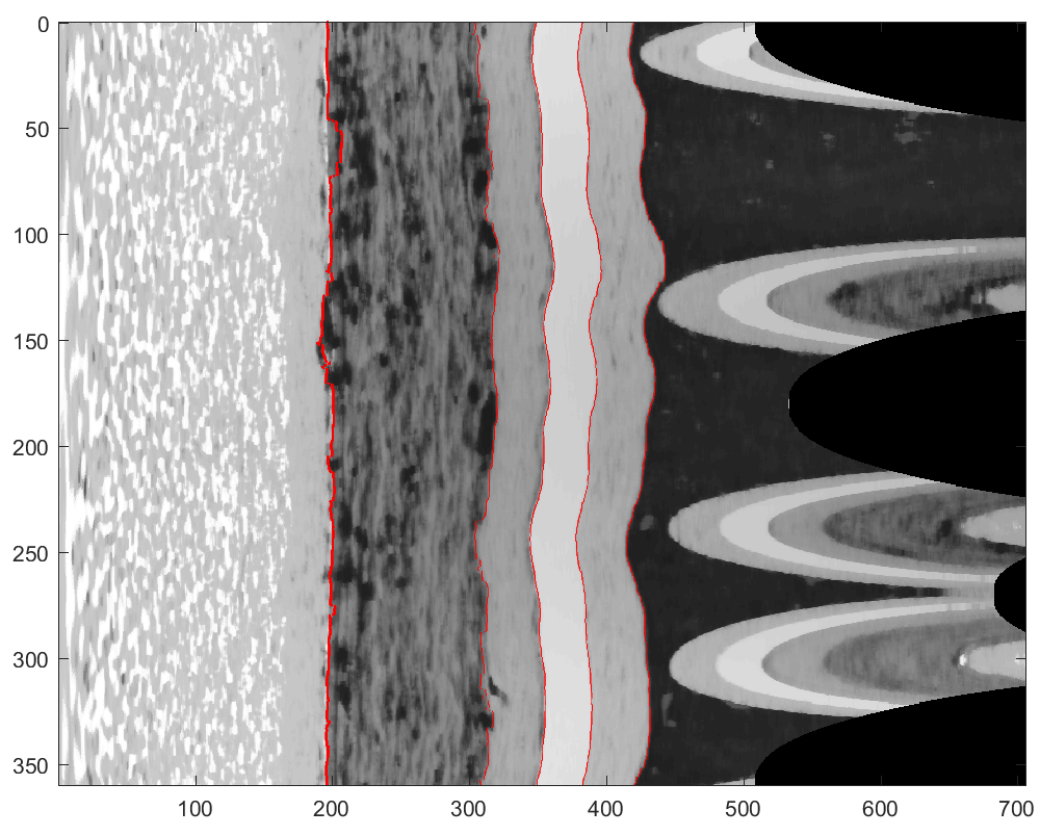
P16082301N257



**P16082301N257 unwrapped**

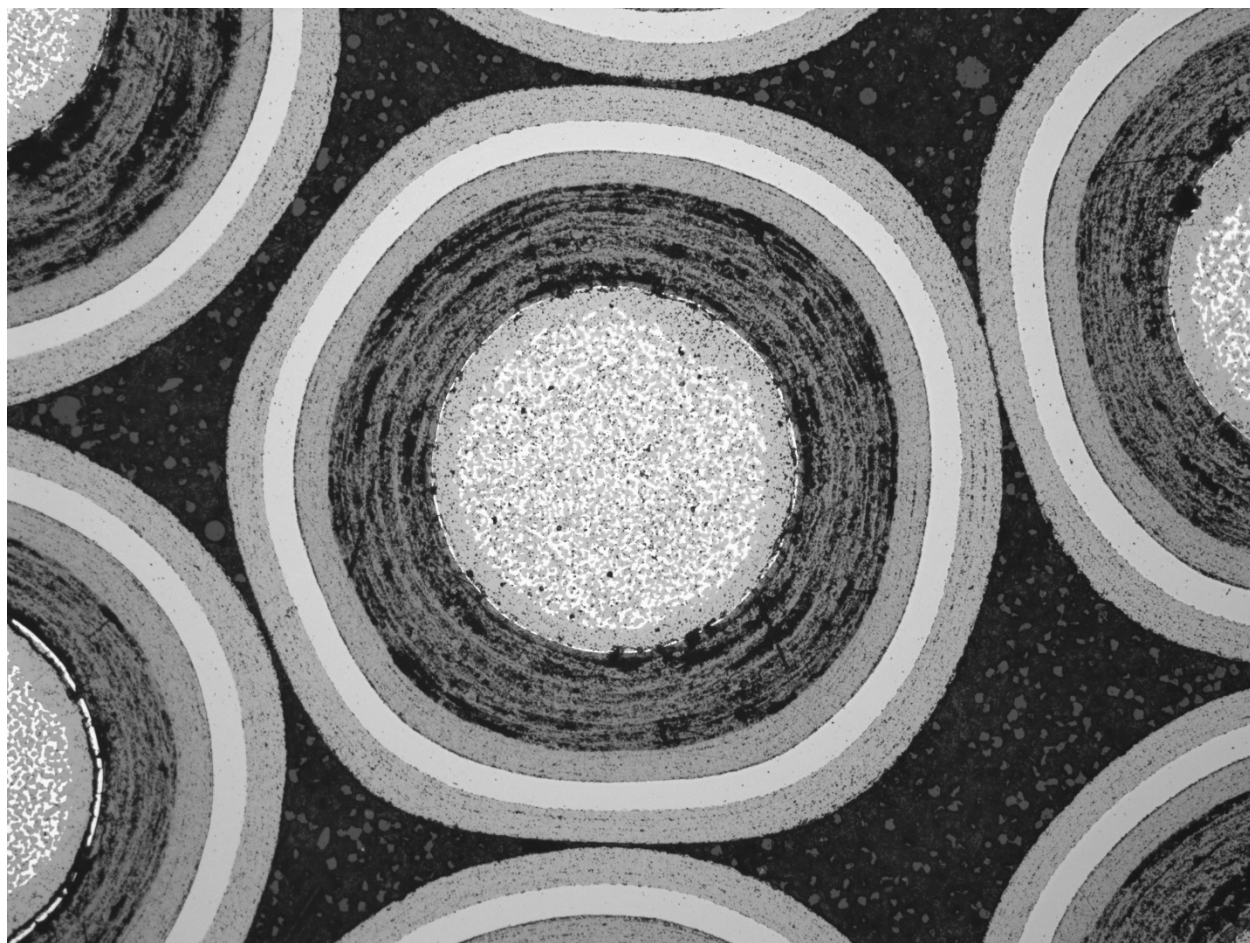


P16082301N259

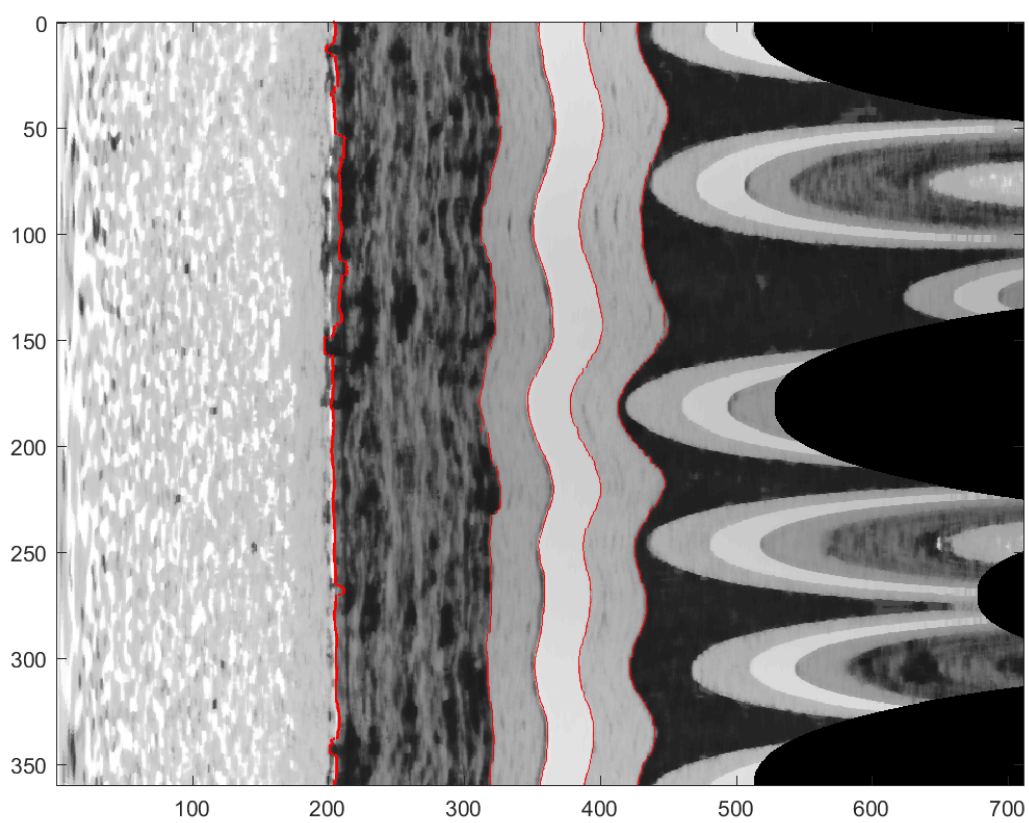


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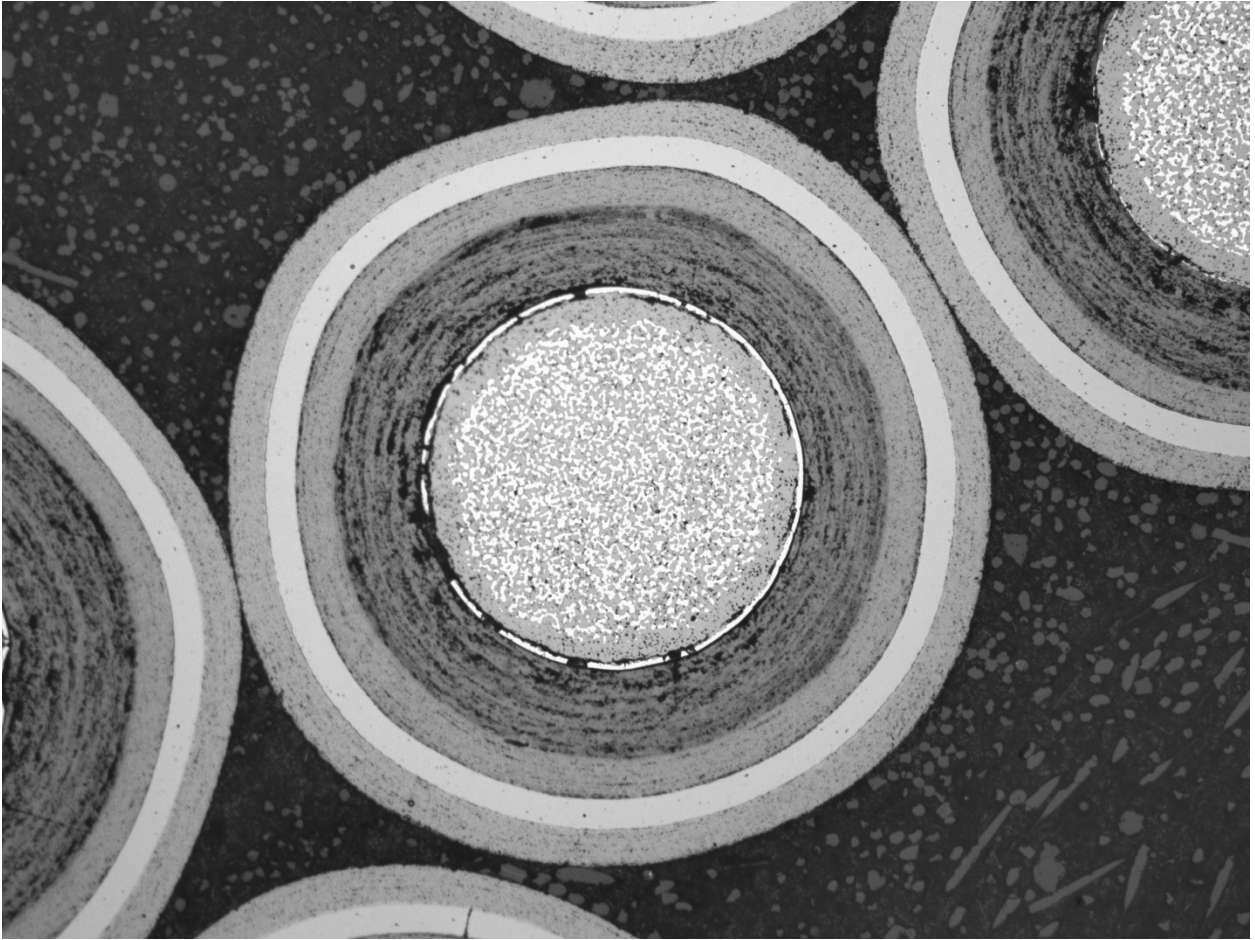




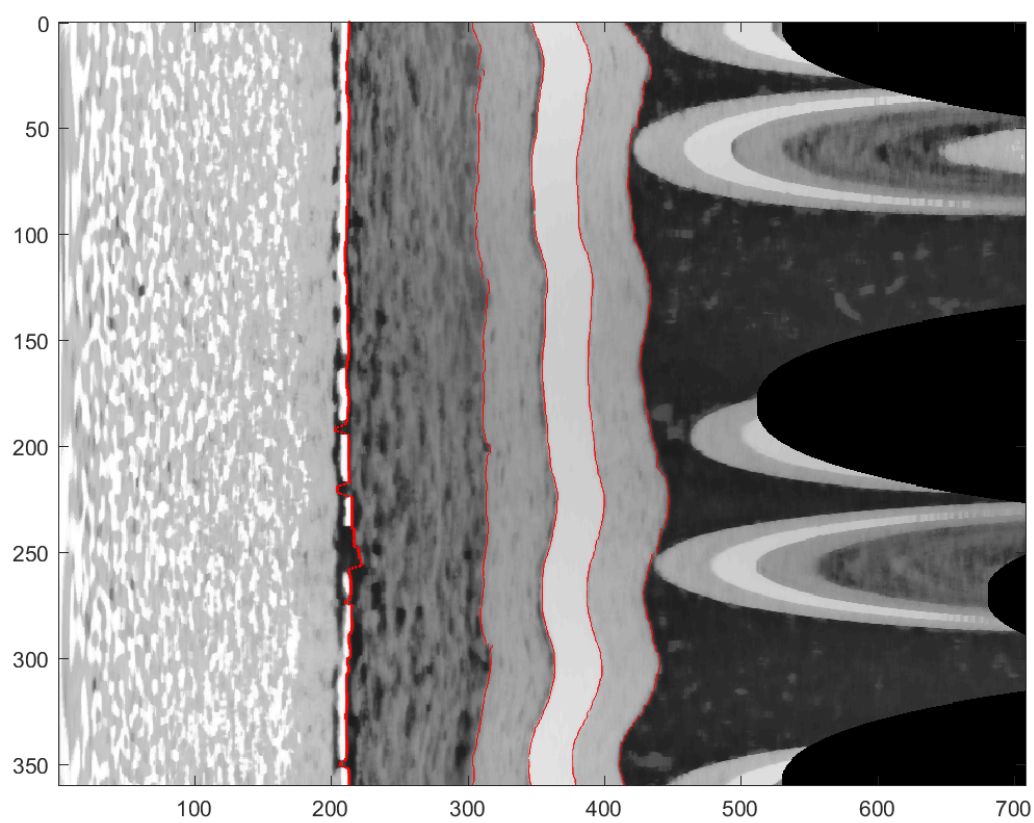
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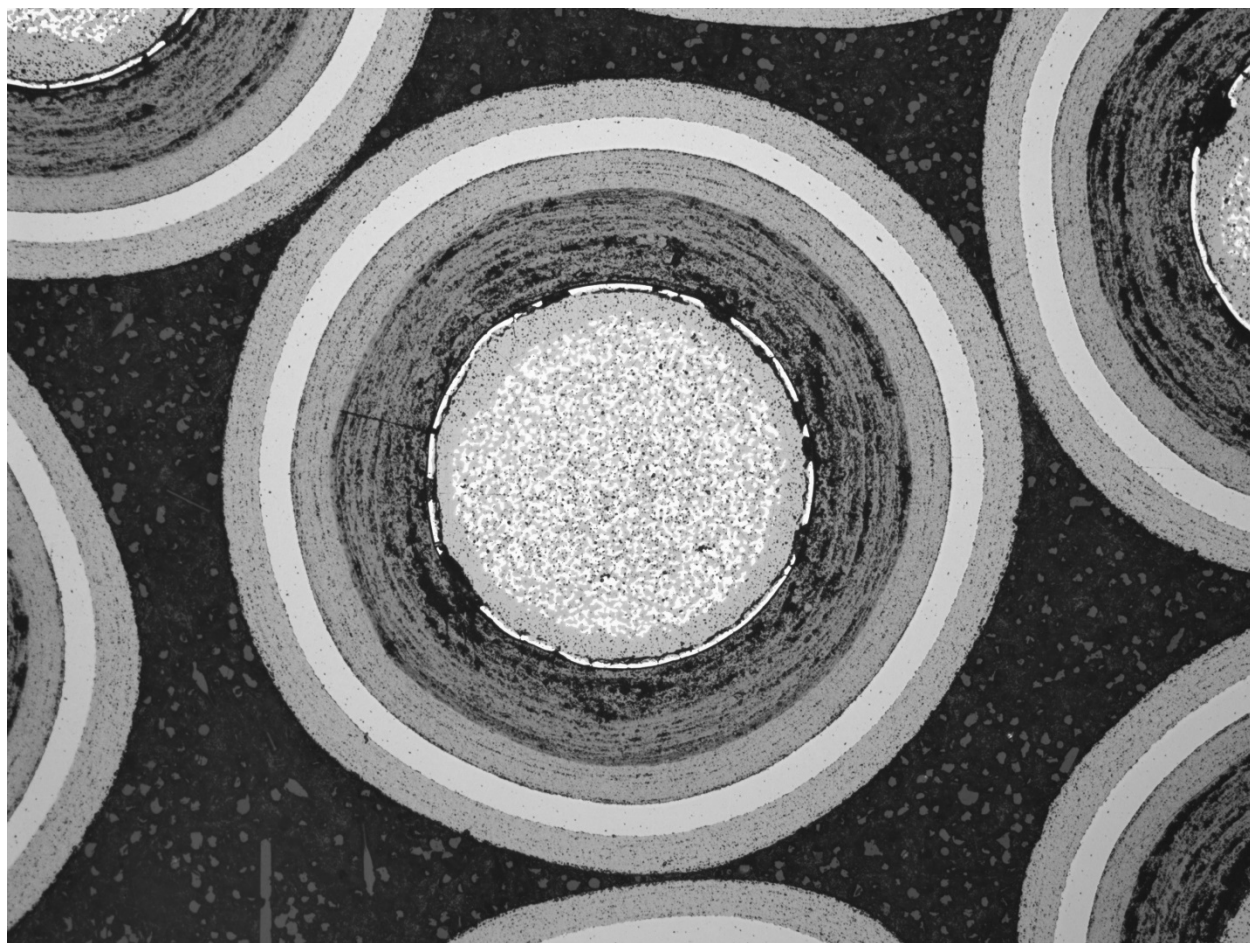
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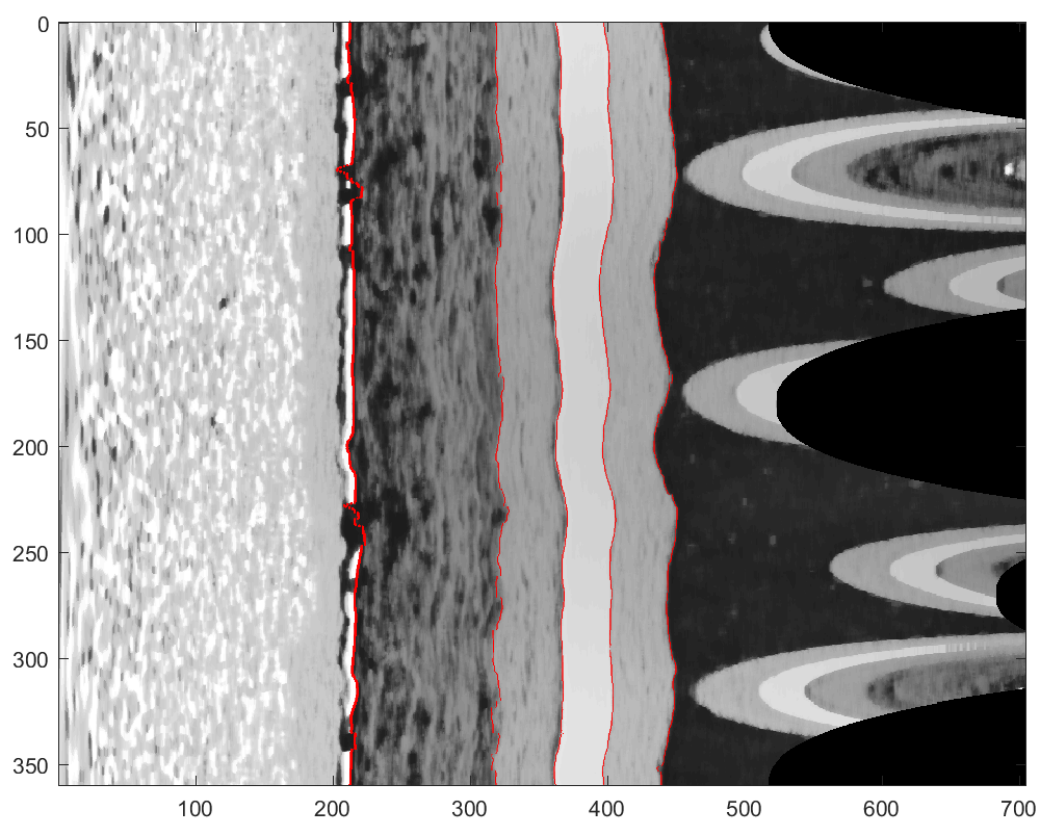
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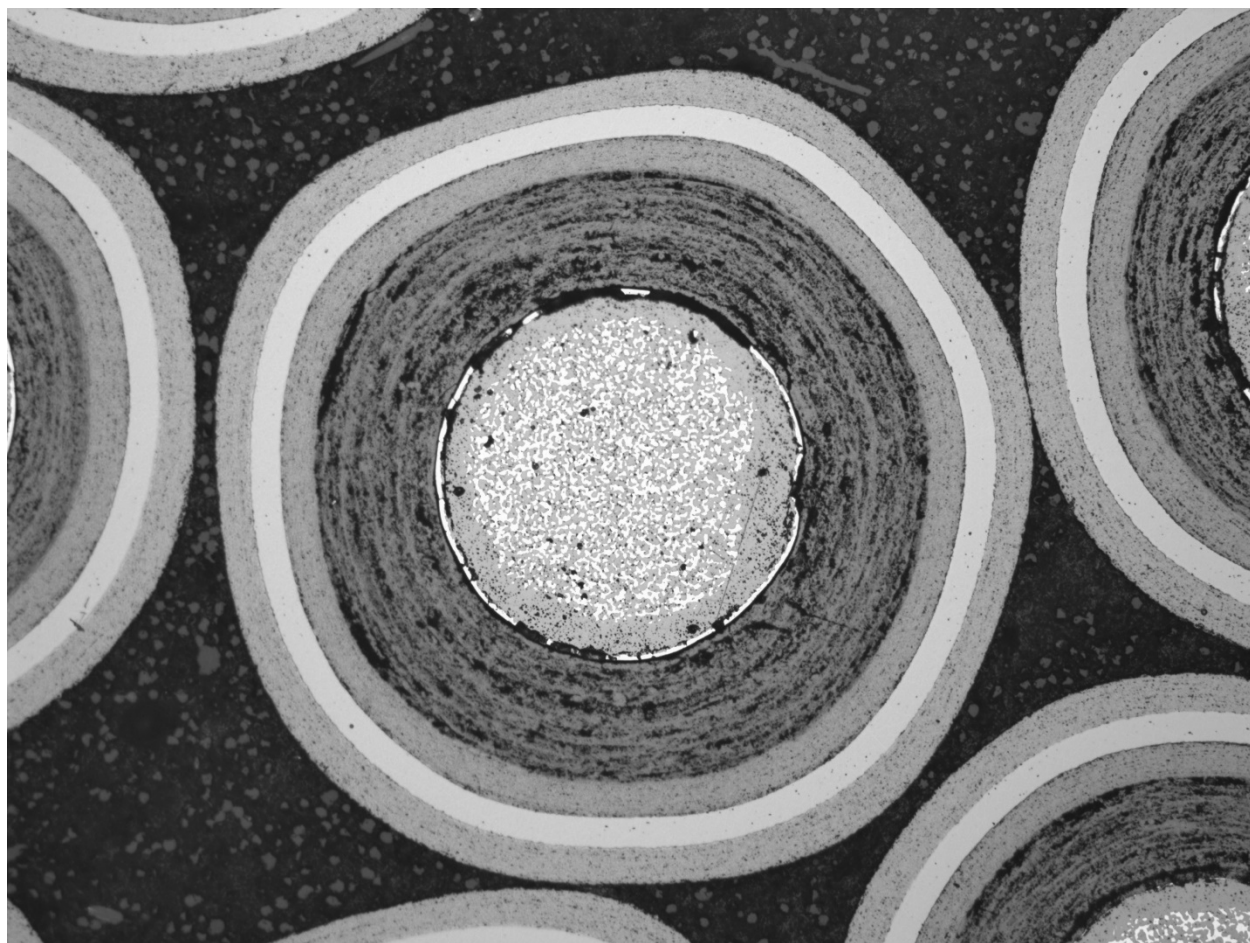


P16082301N264

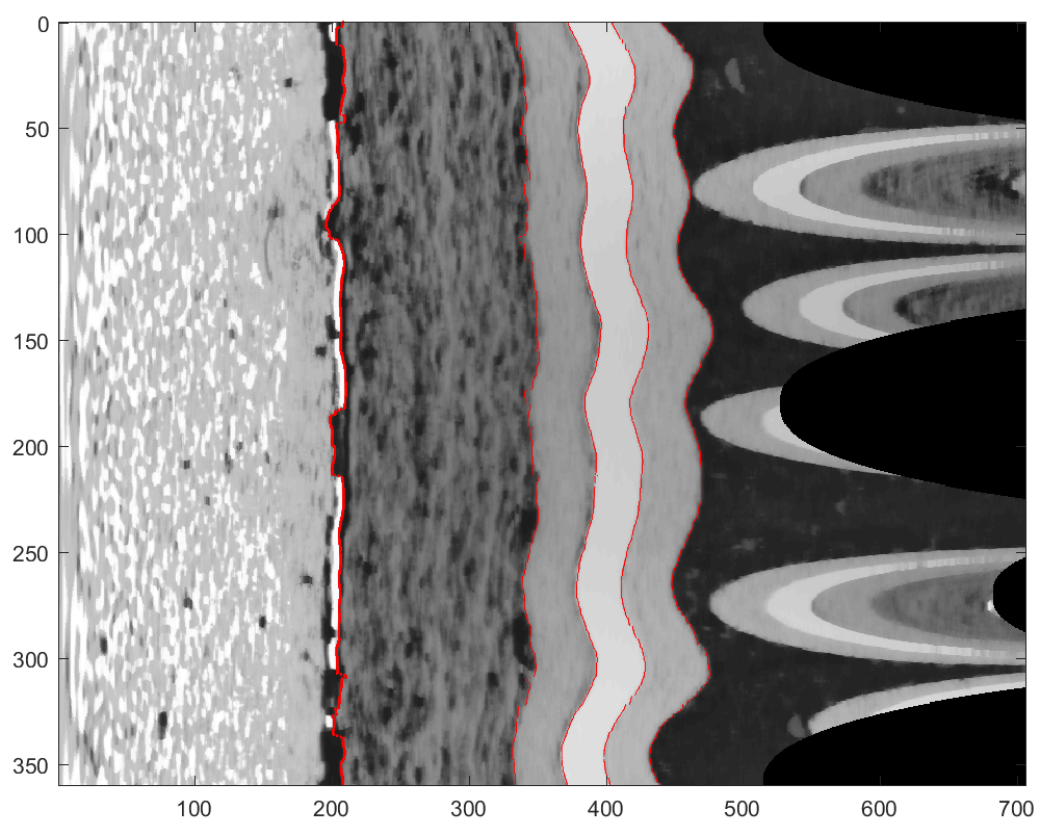


**P16082301N264 unwrapped**

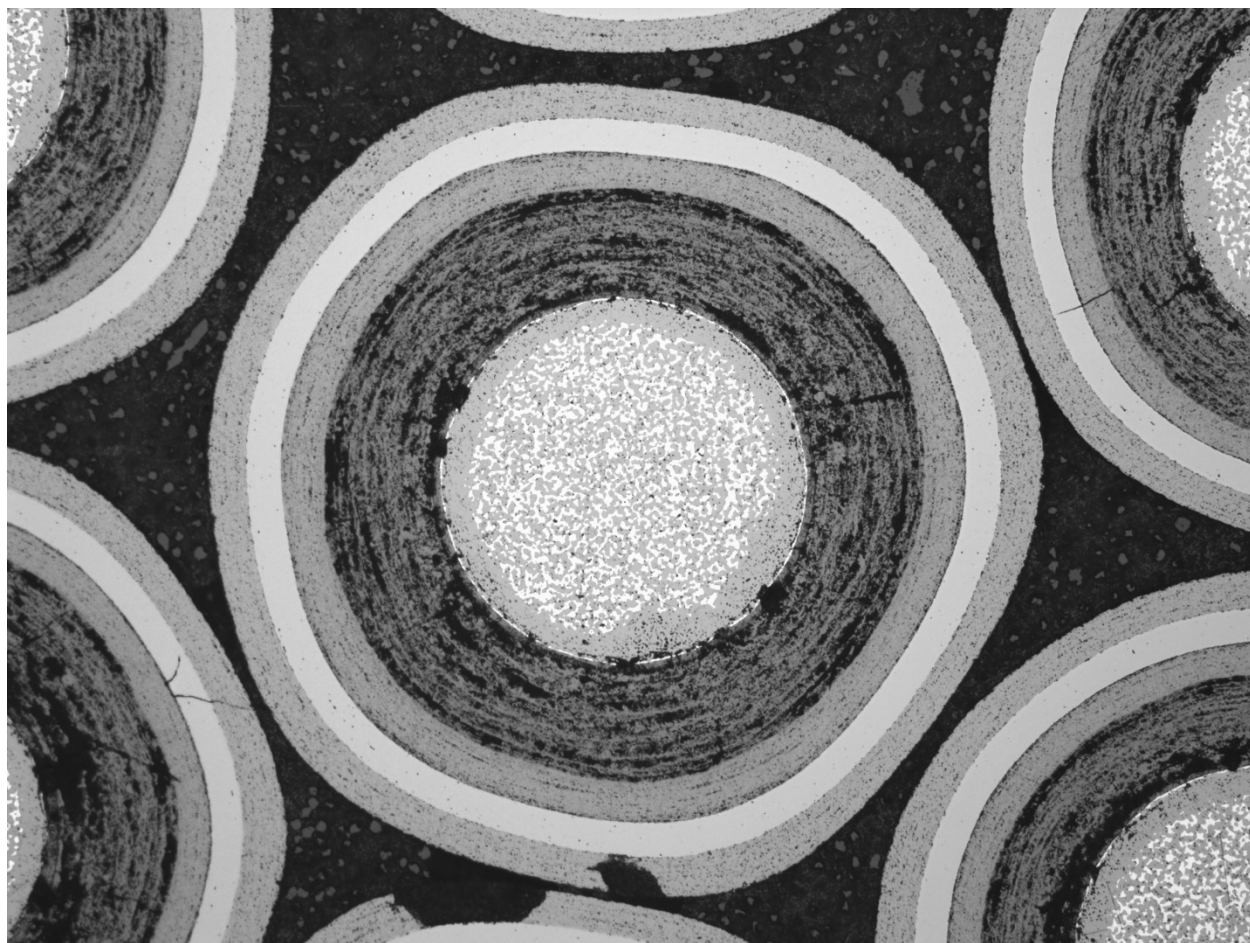




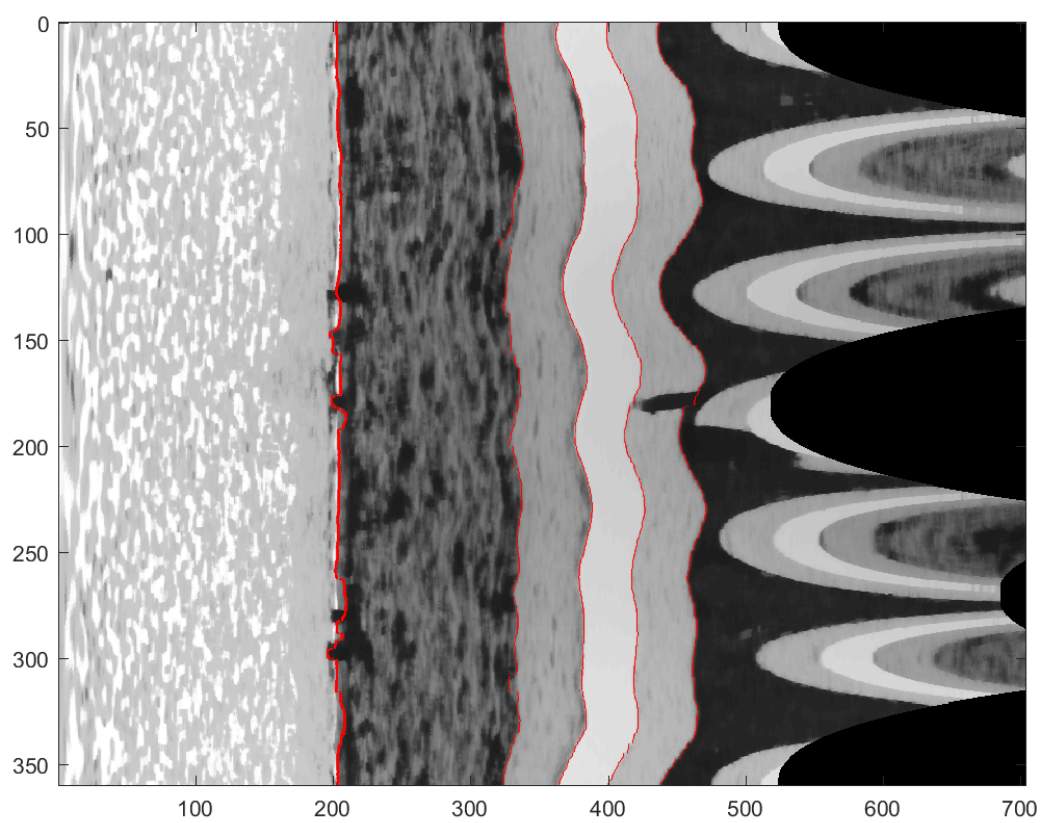
P16082301N265



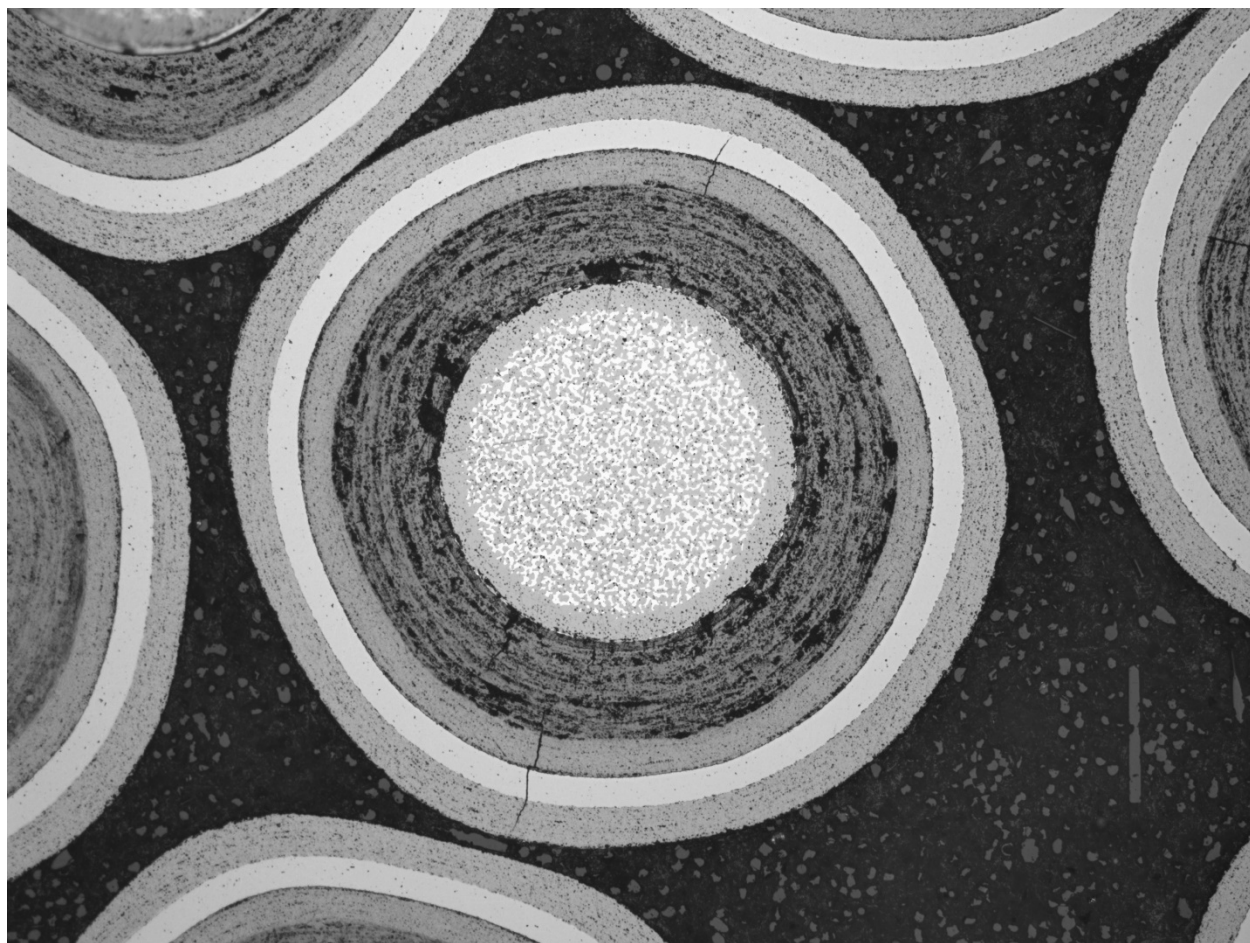
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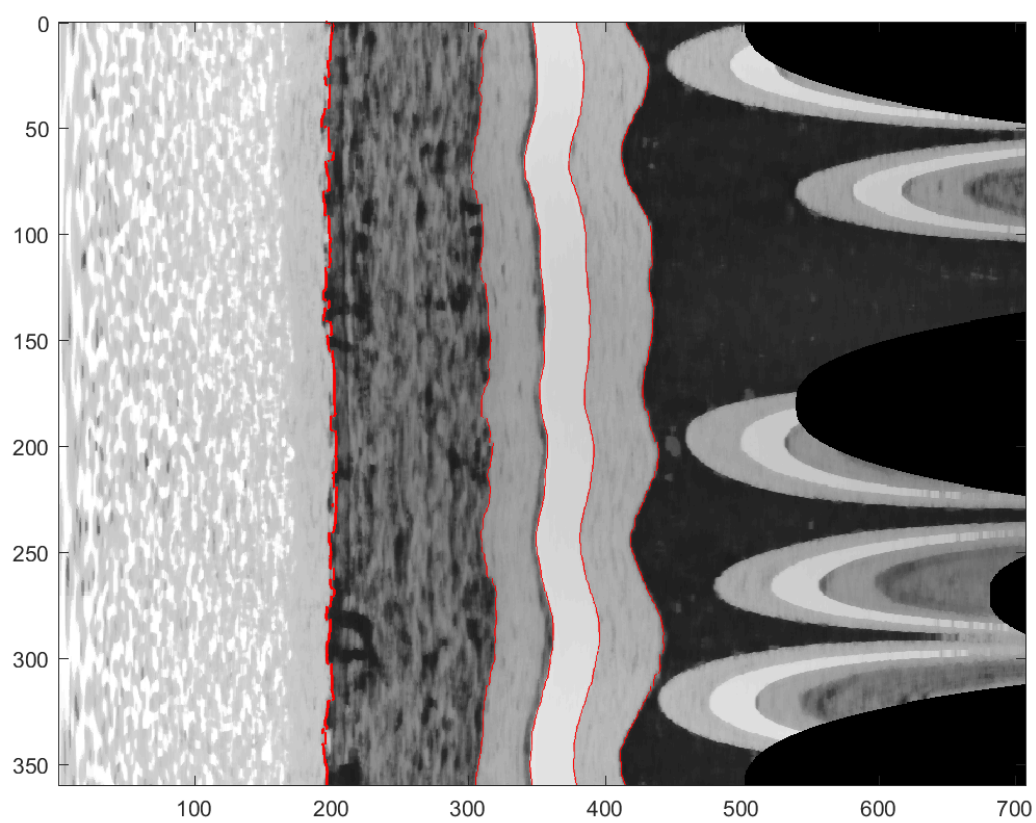
P16082301N266



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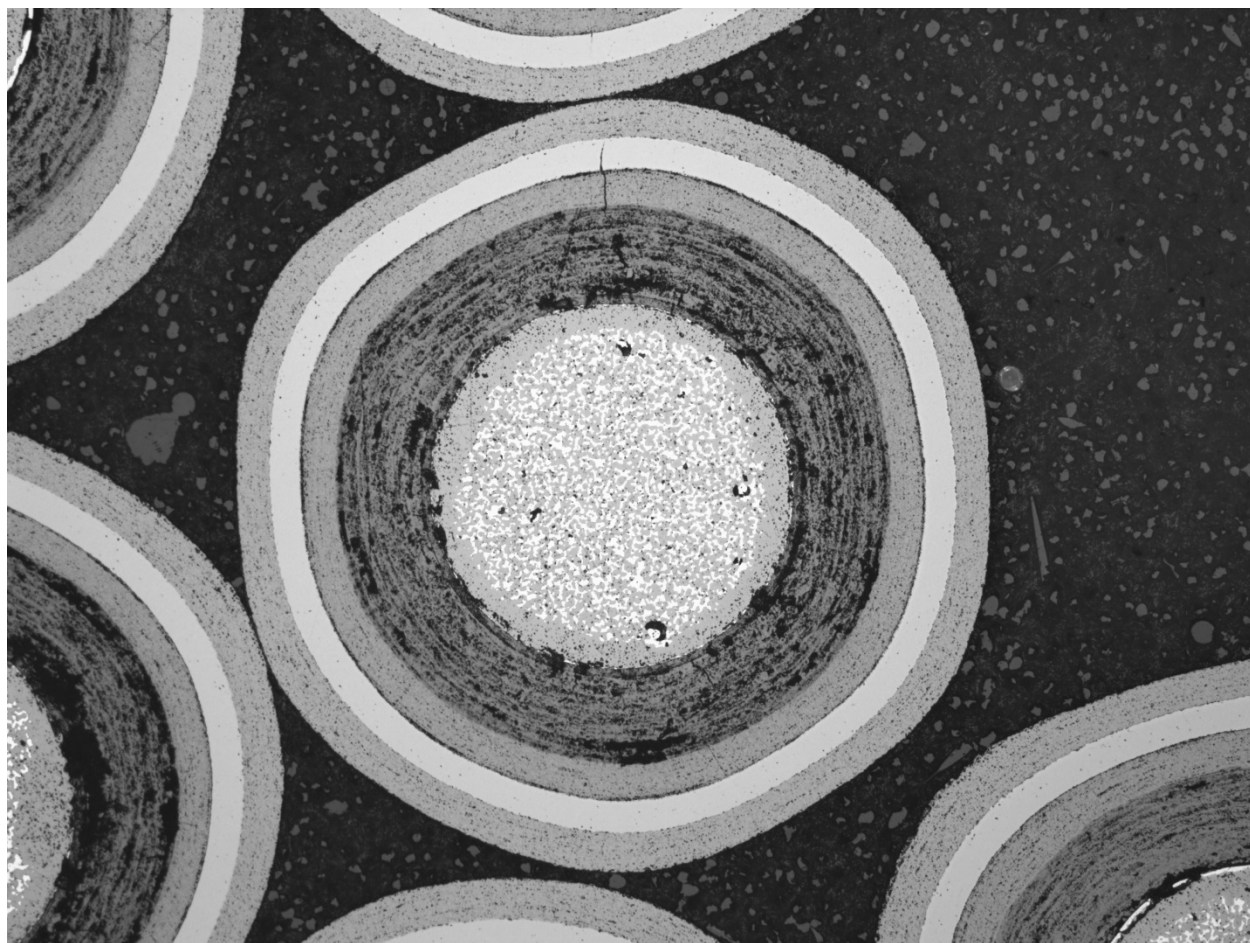


P16082301N268

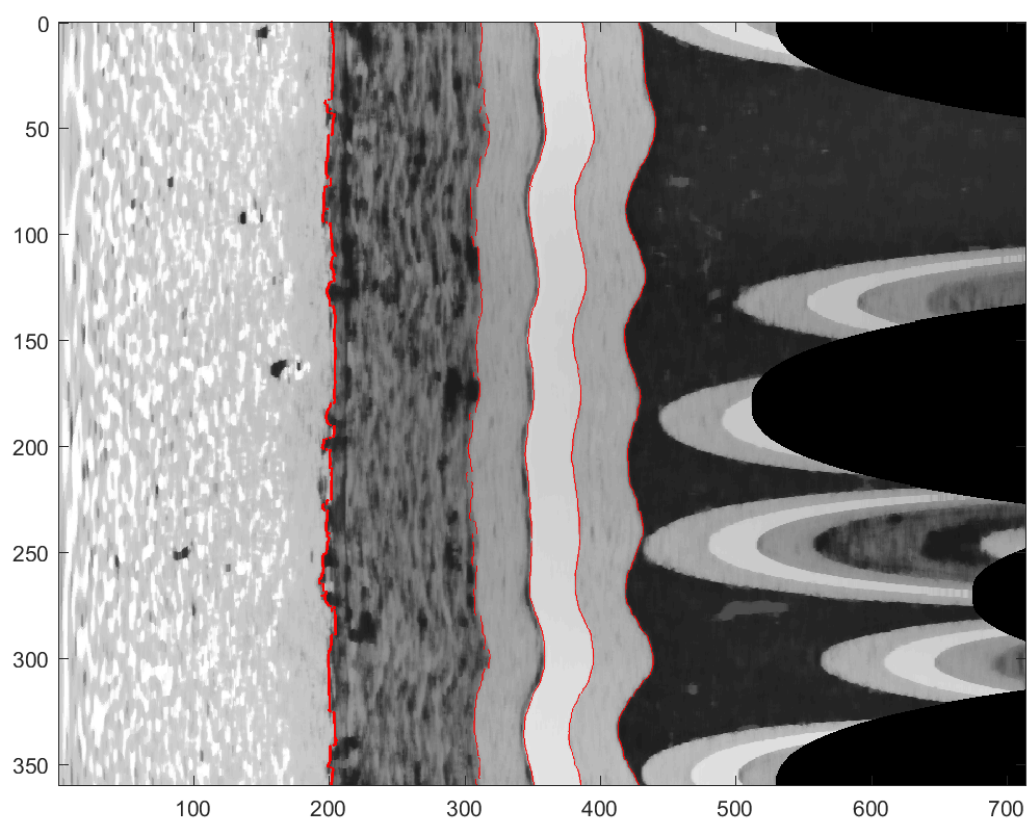


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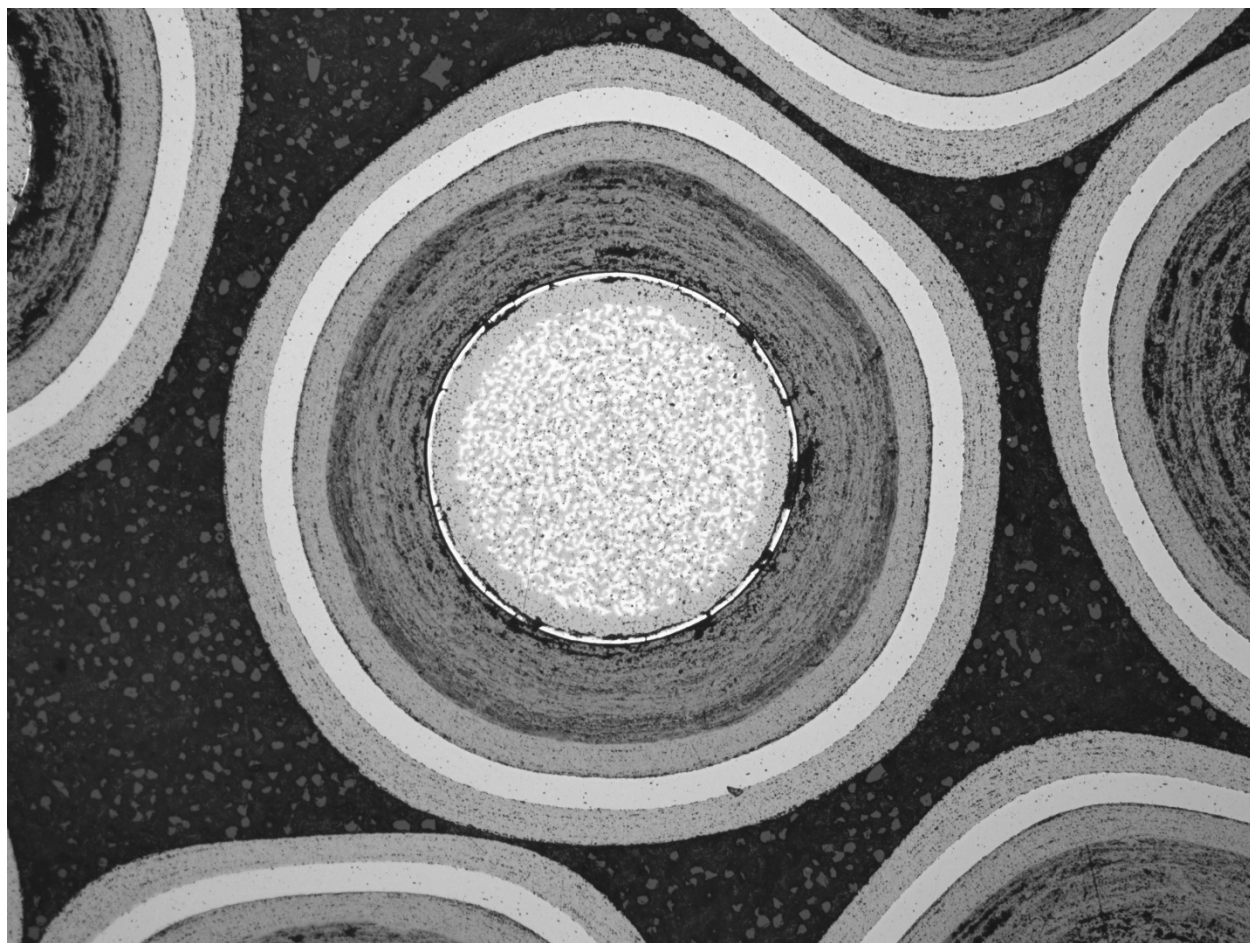




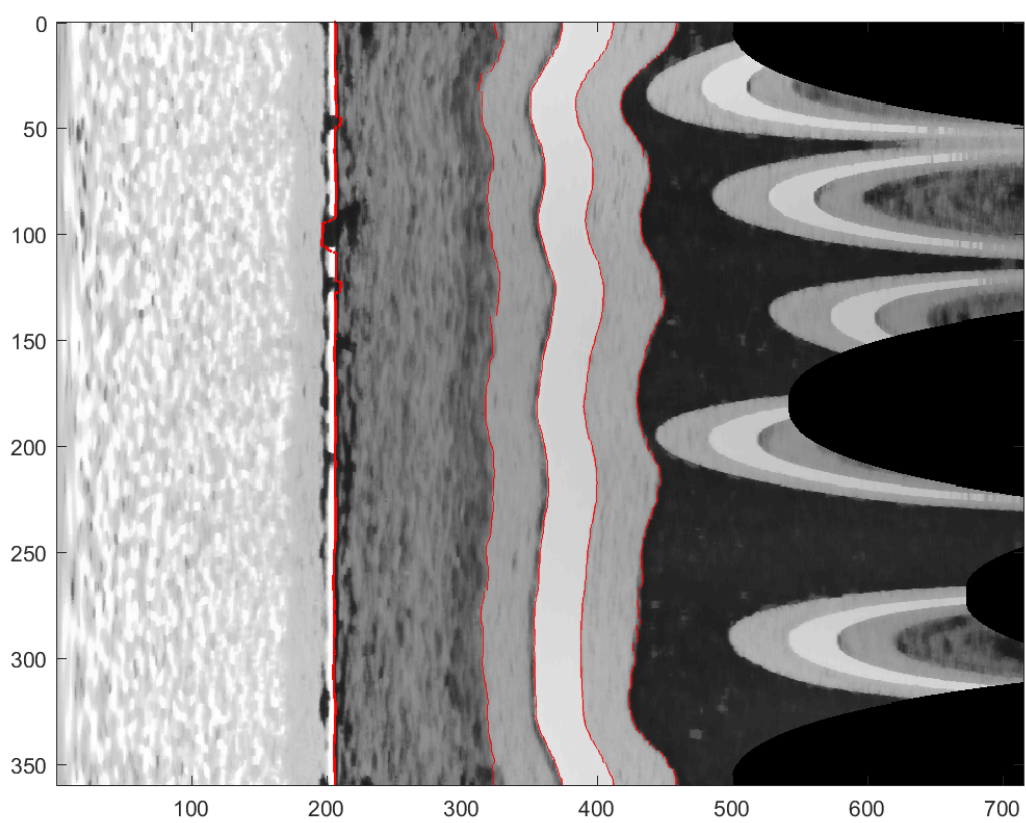
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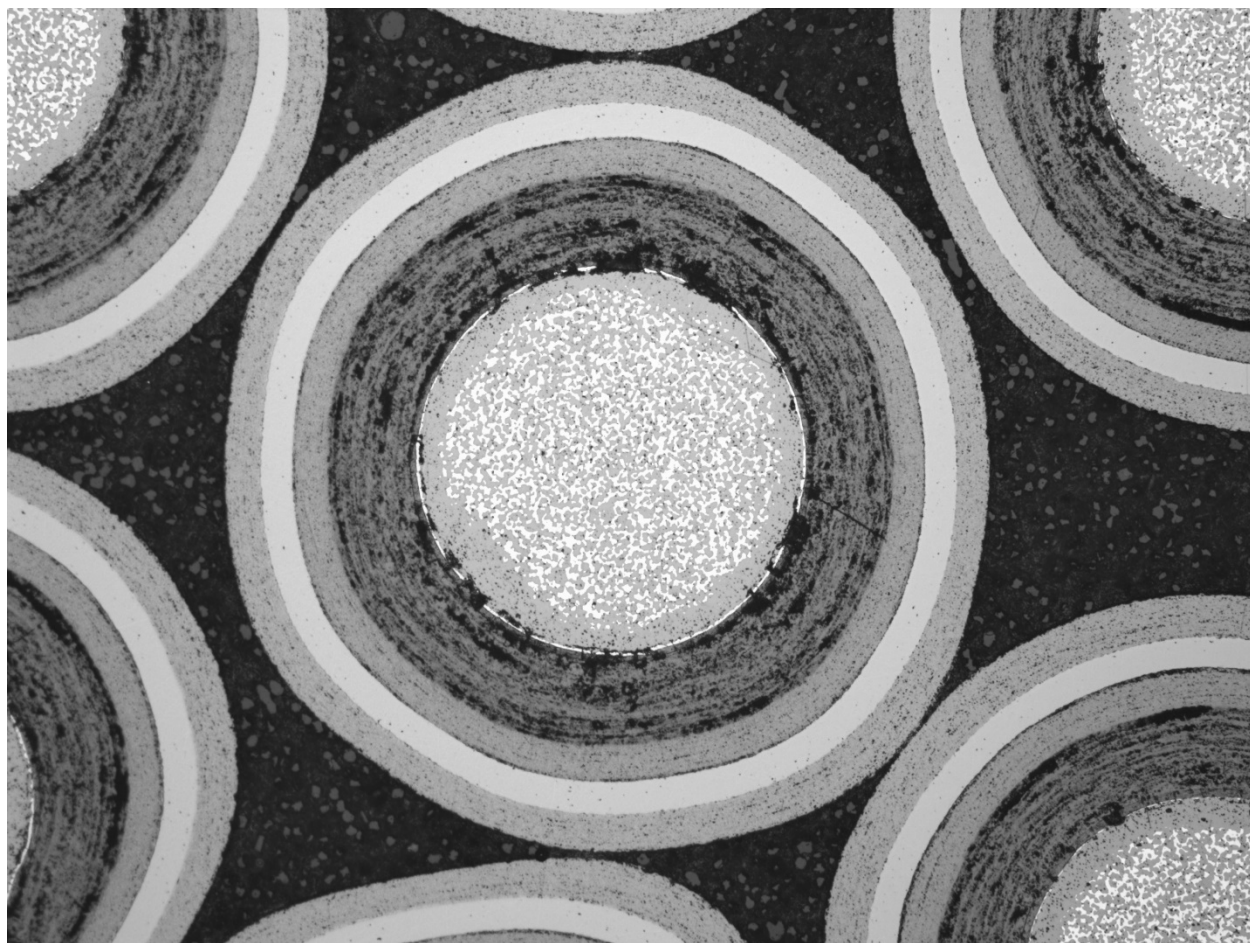
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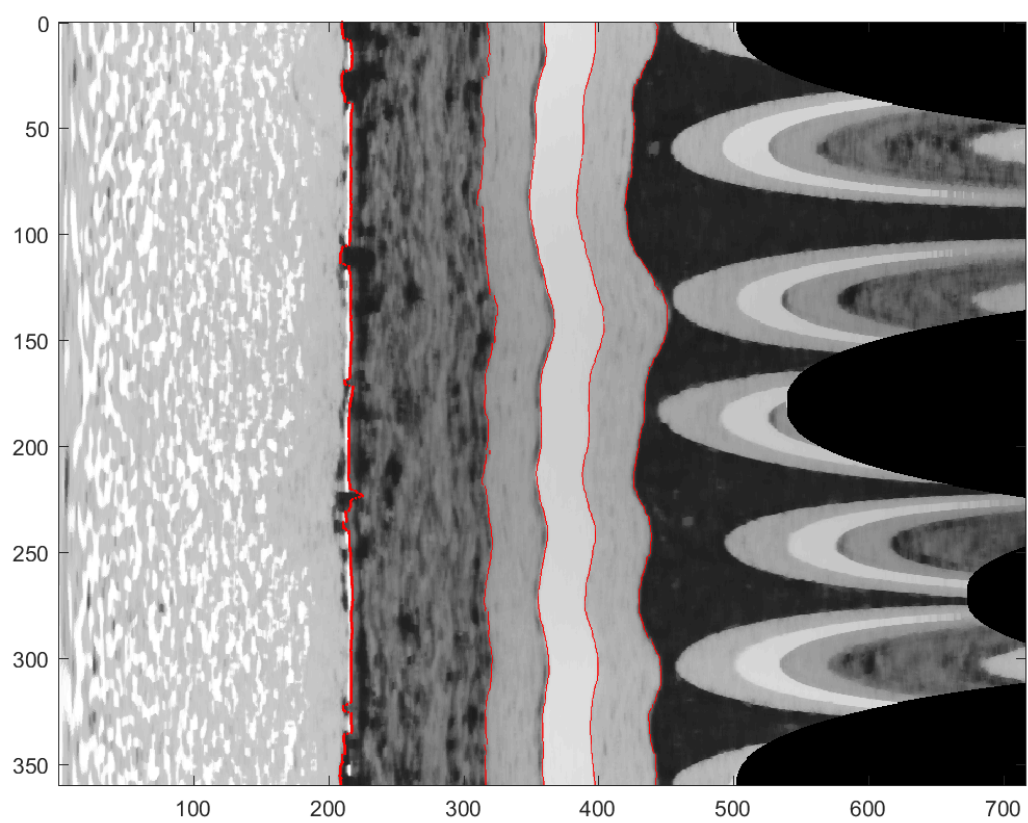
P16082301N270



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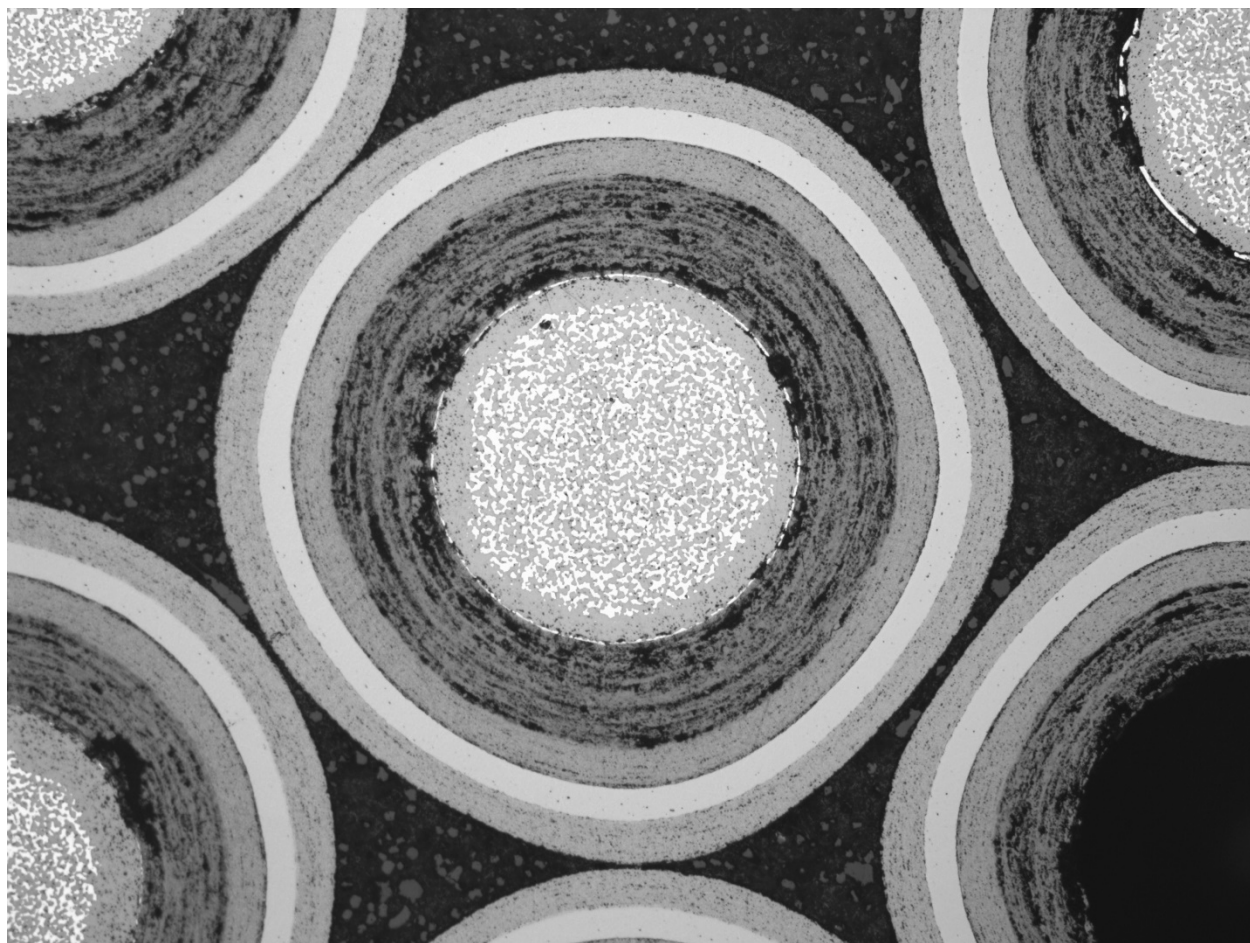


P16082301N271

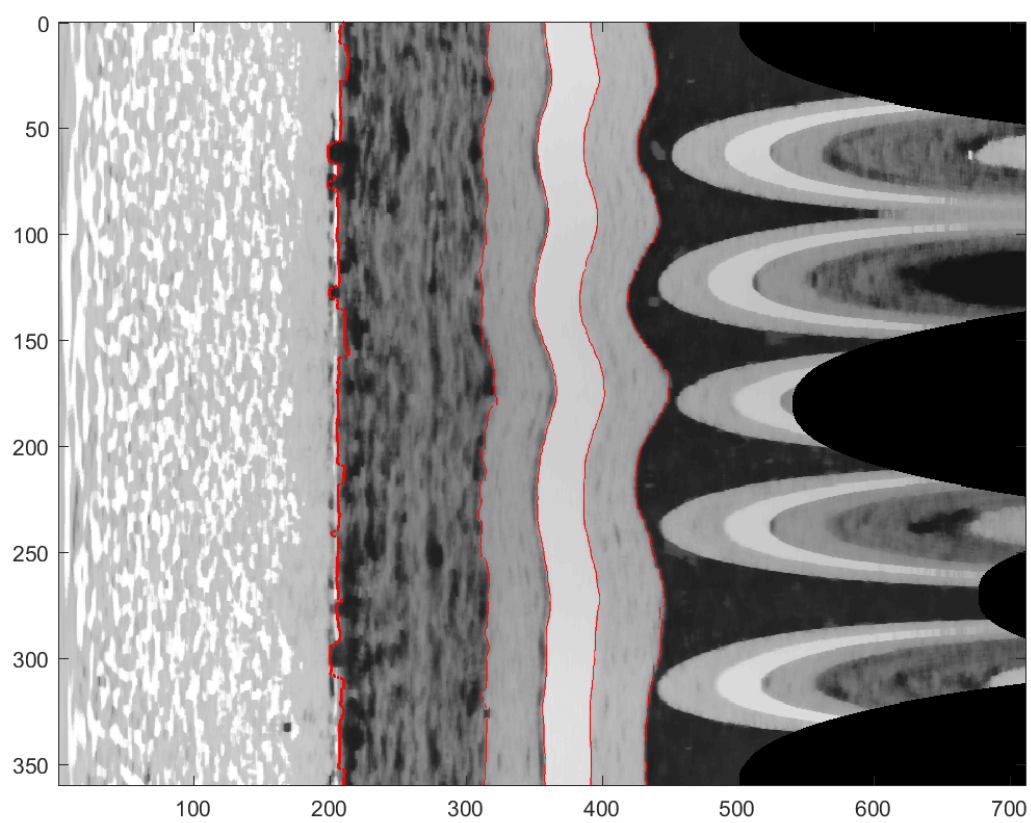


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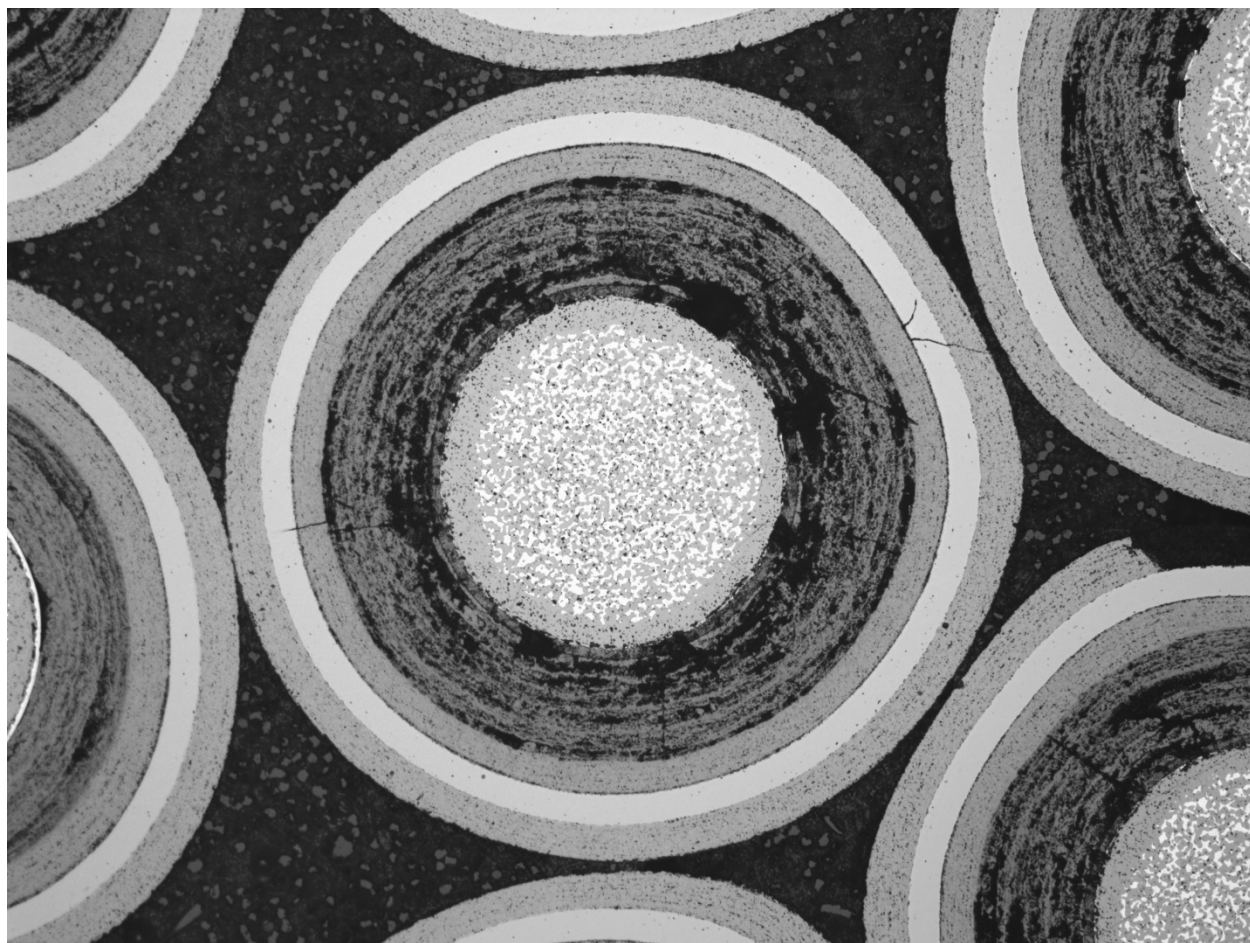




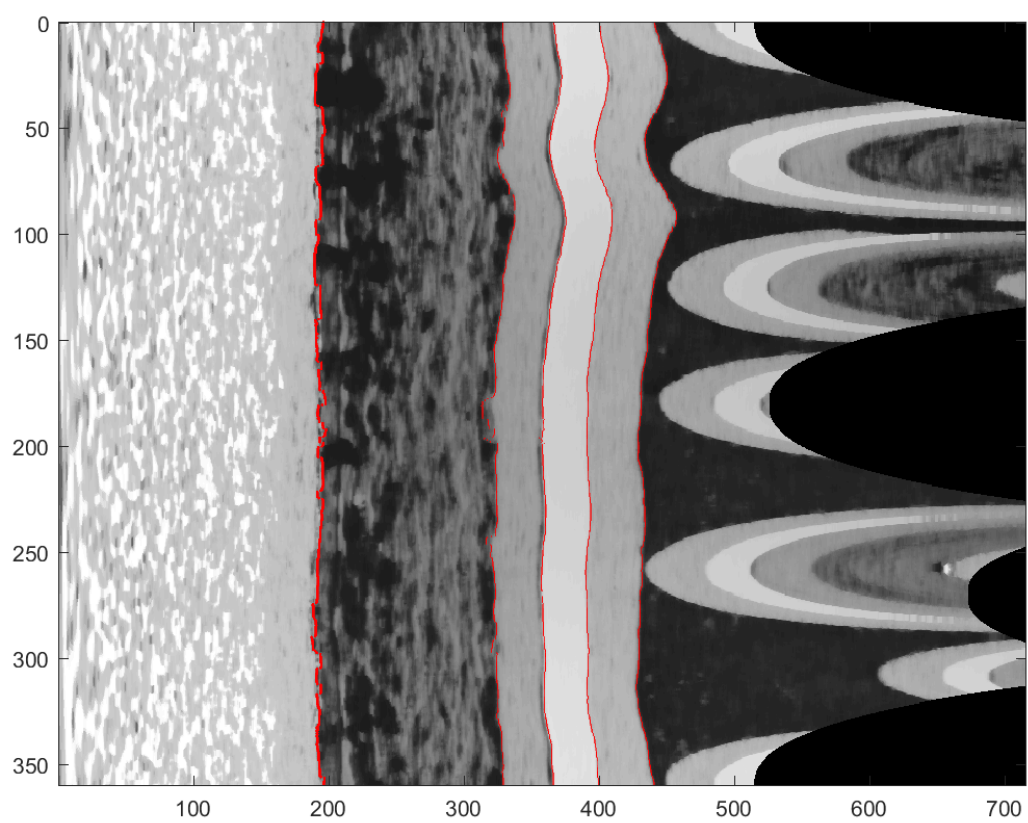
P16082301N272



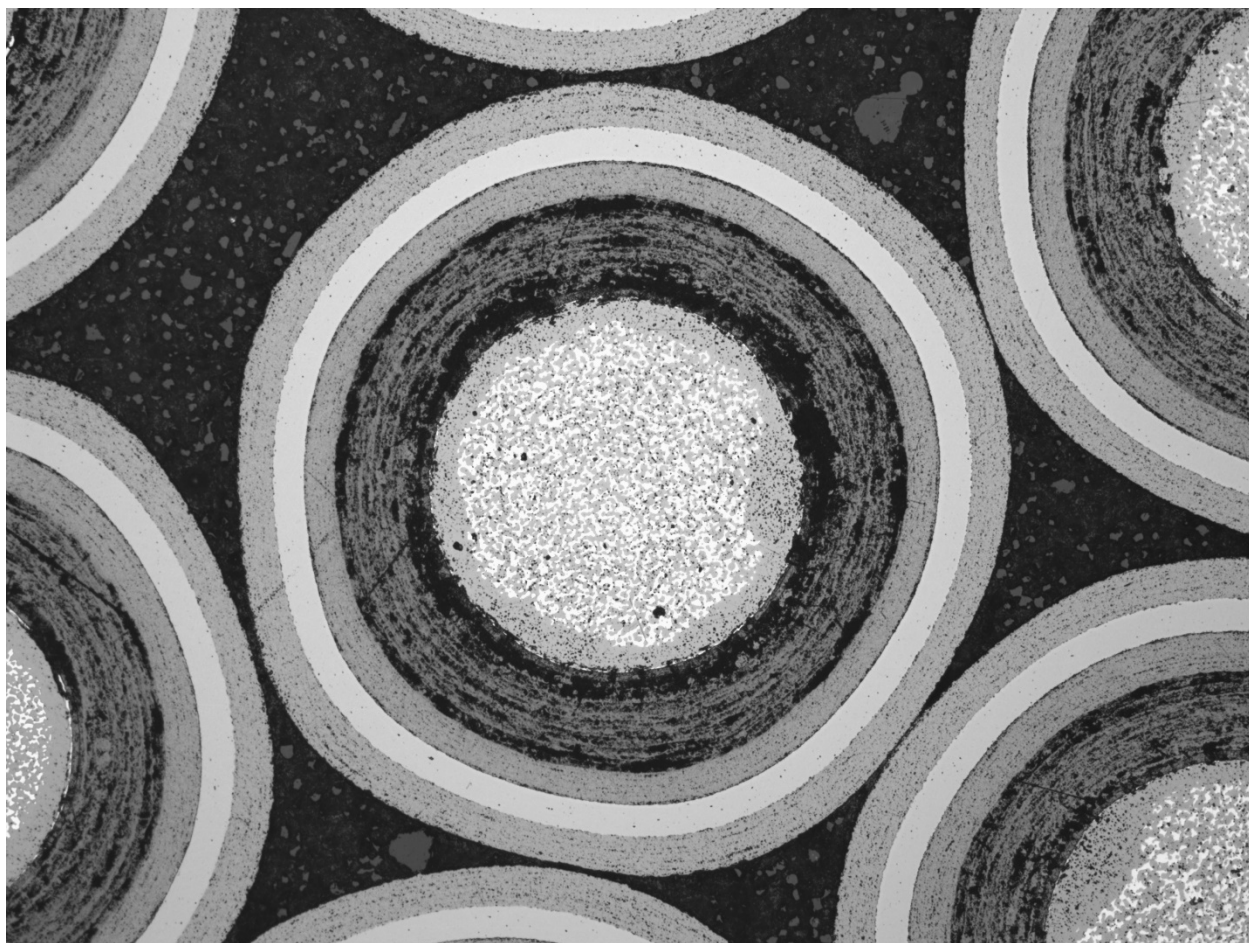
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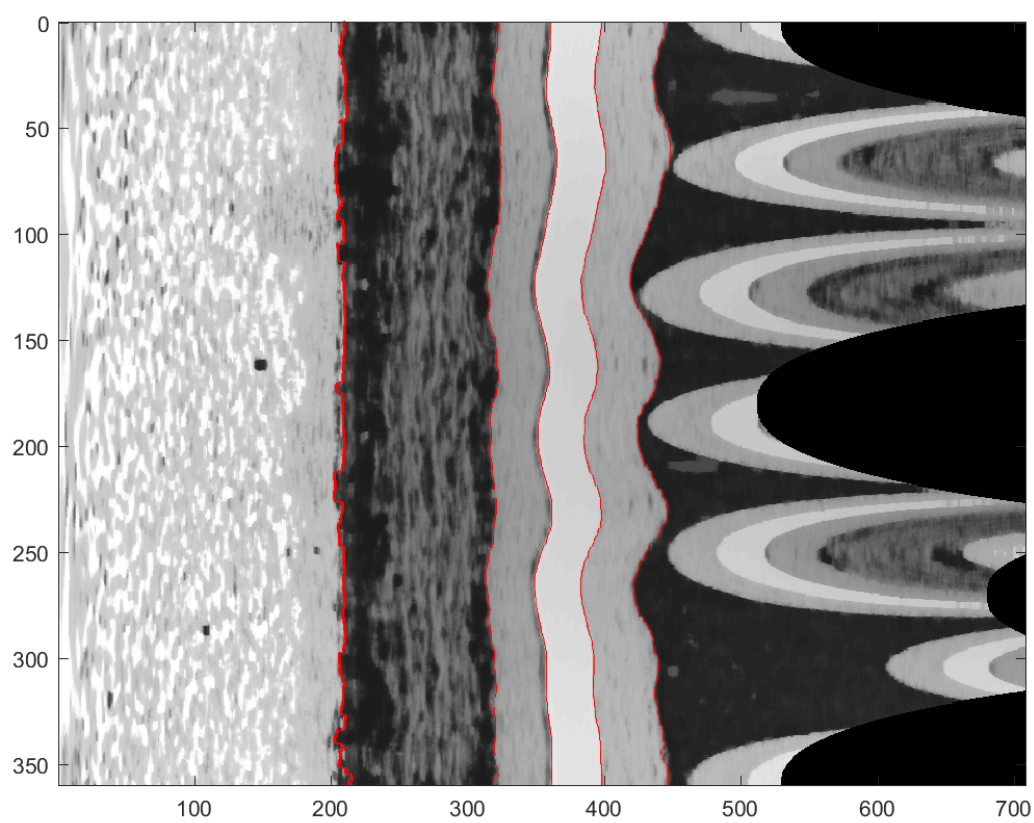
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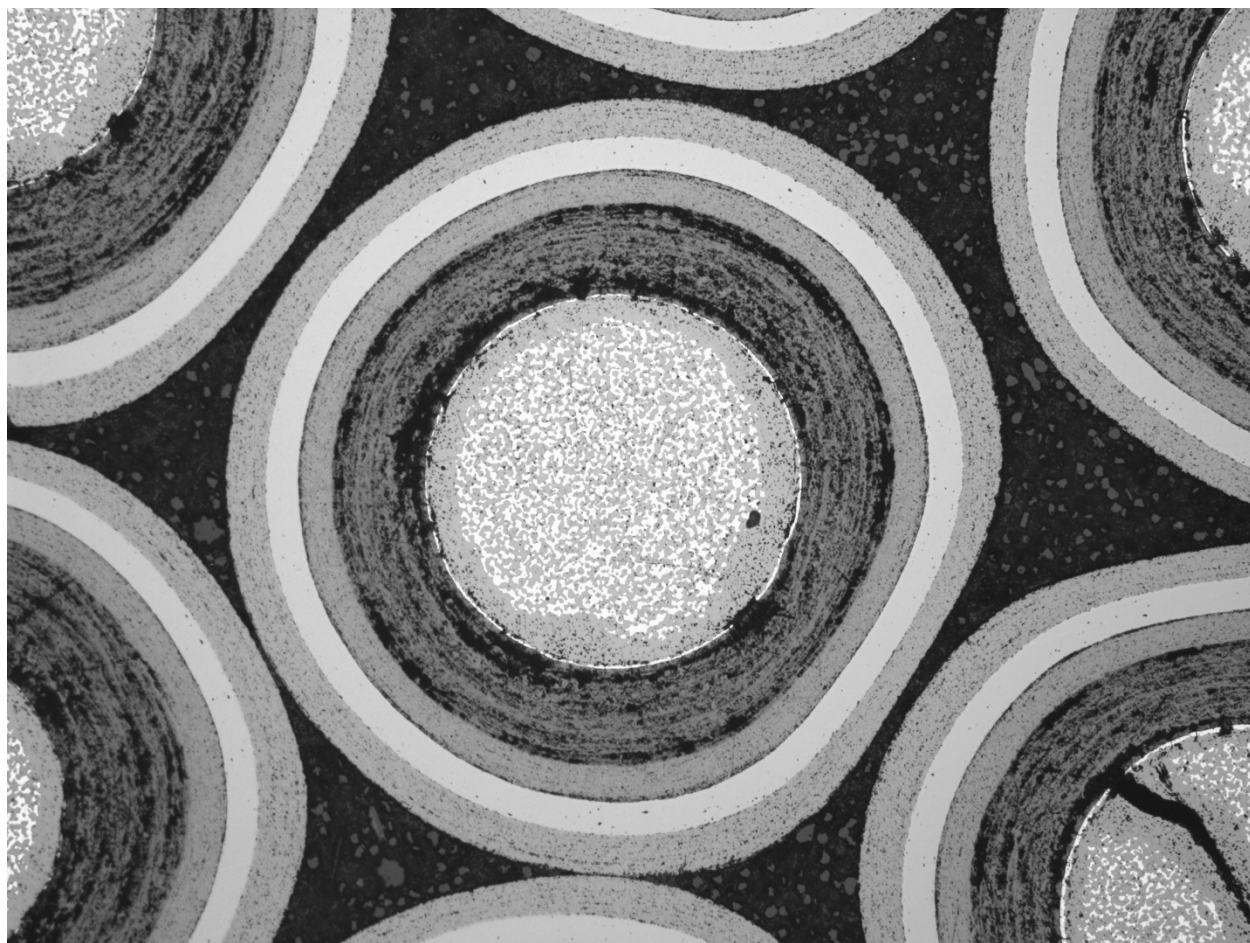


P16082301N274

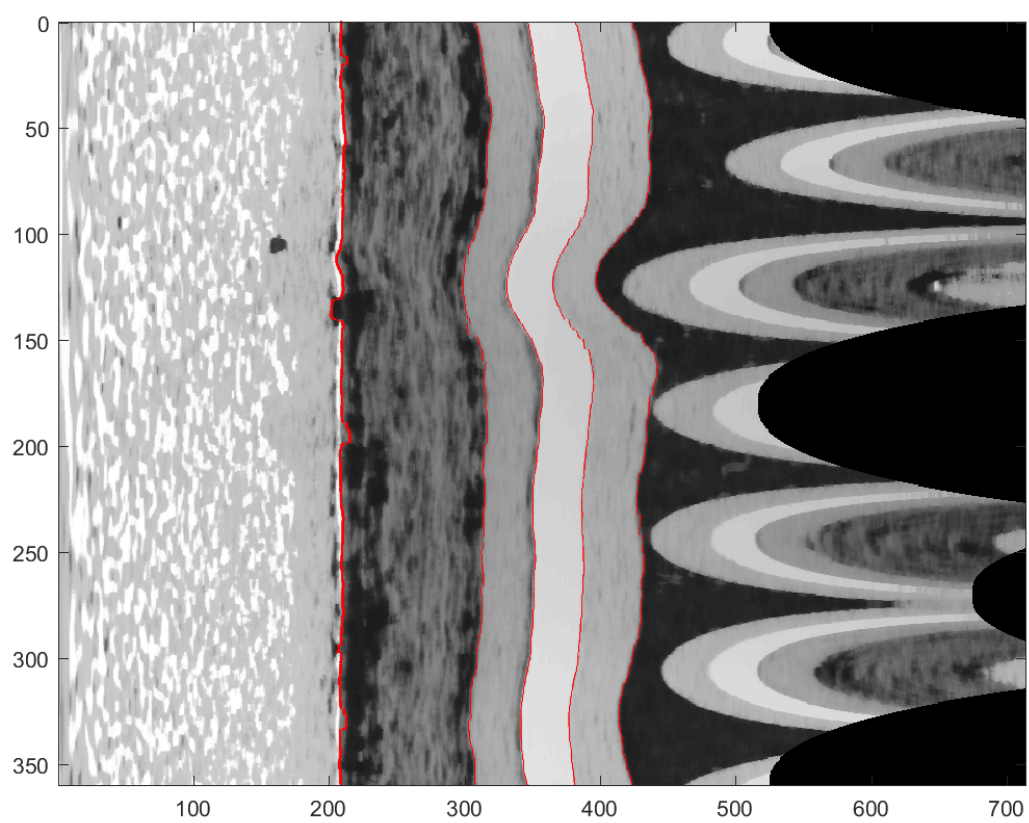


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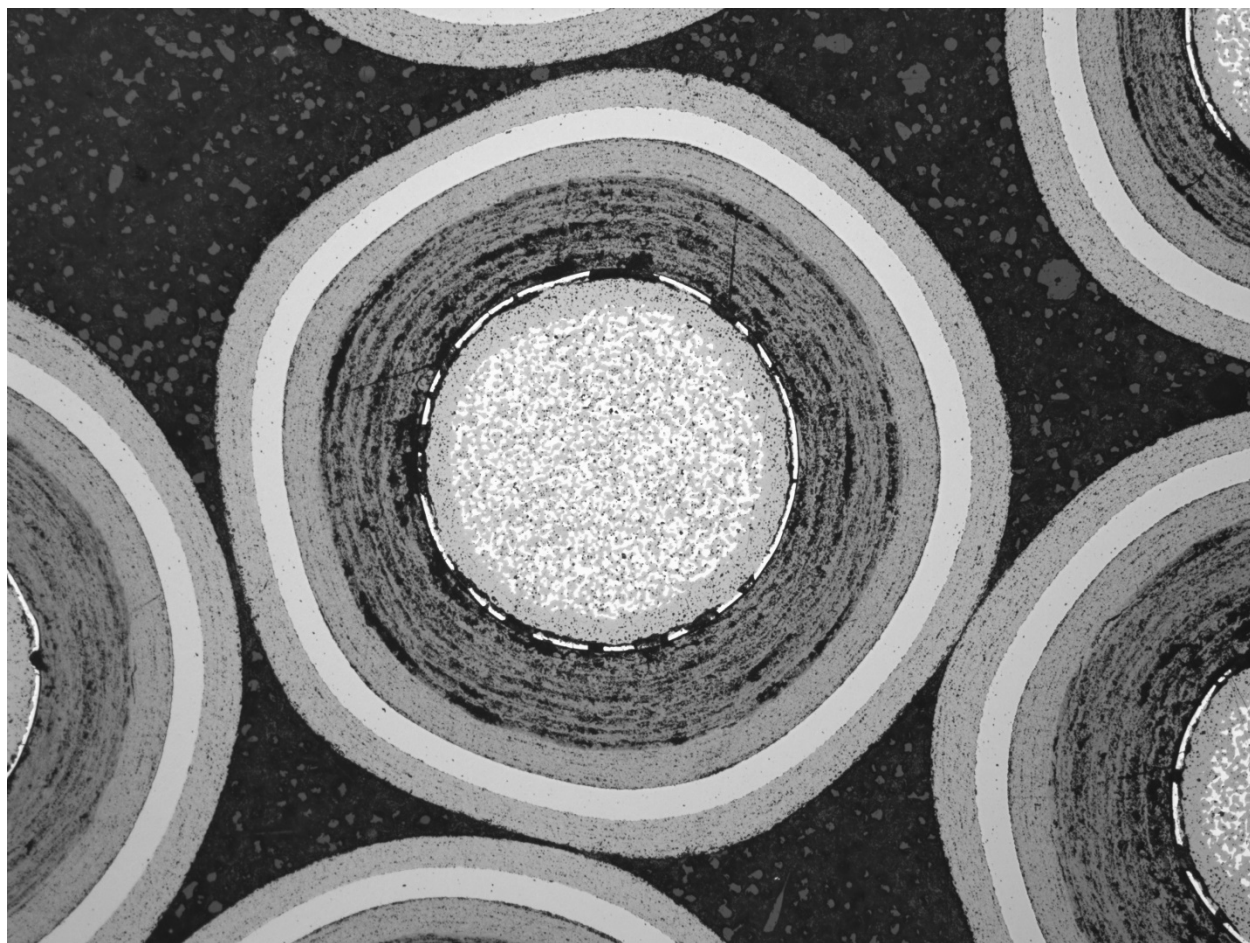




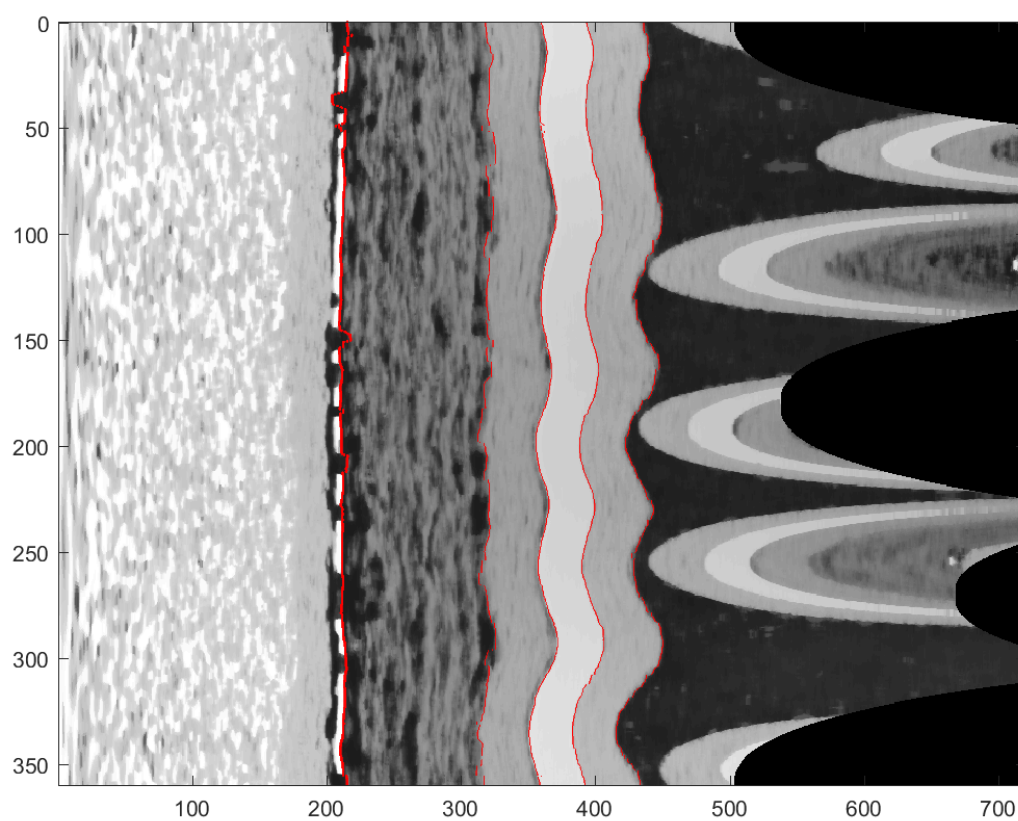
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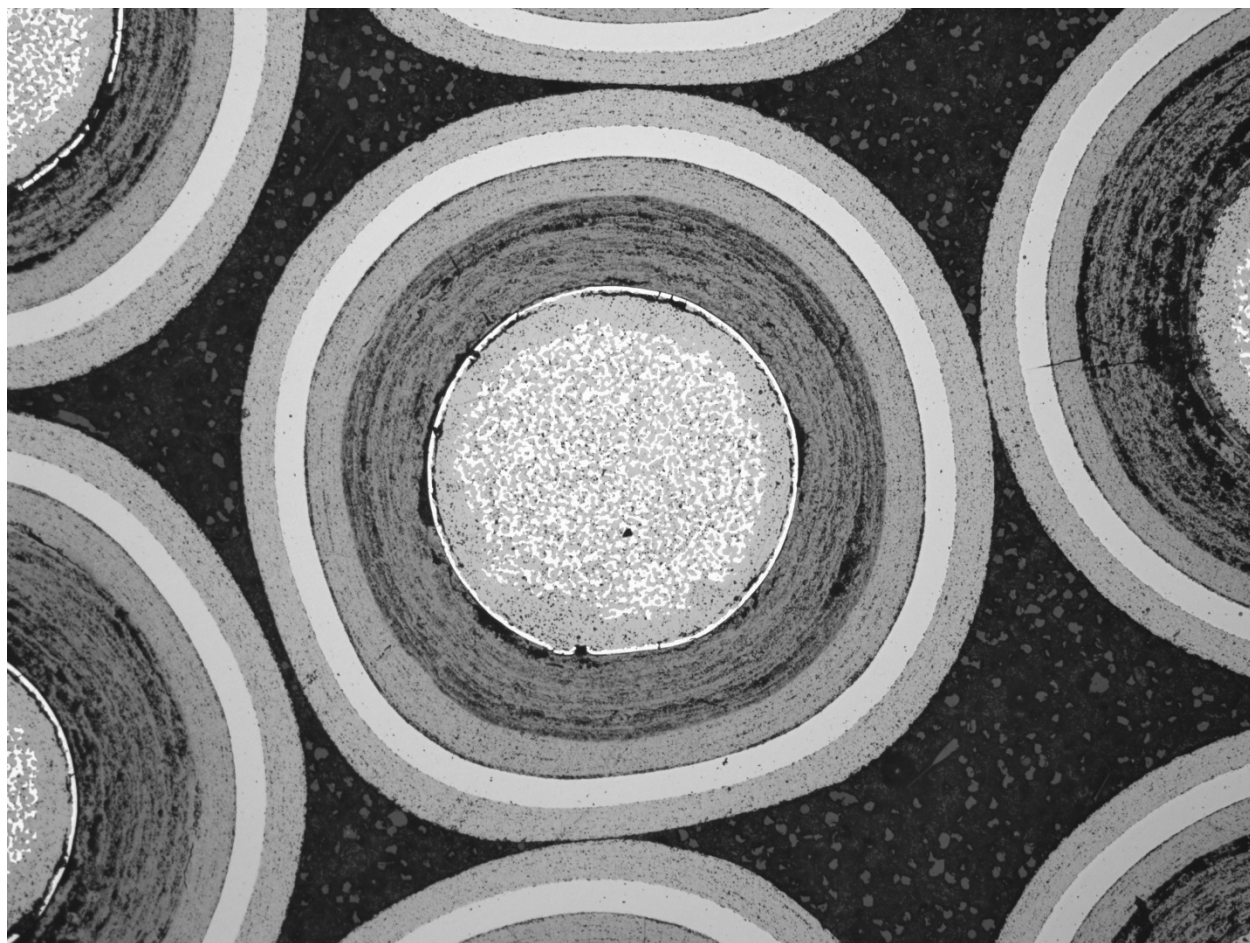
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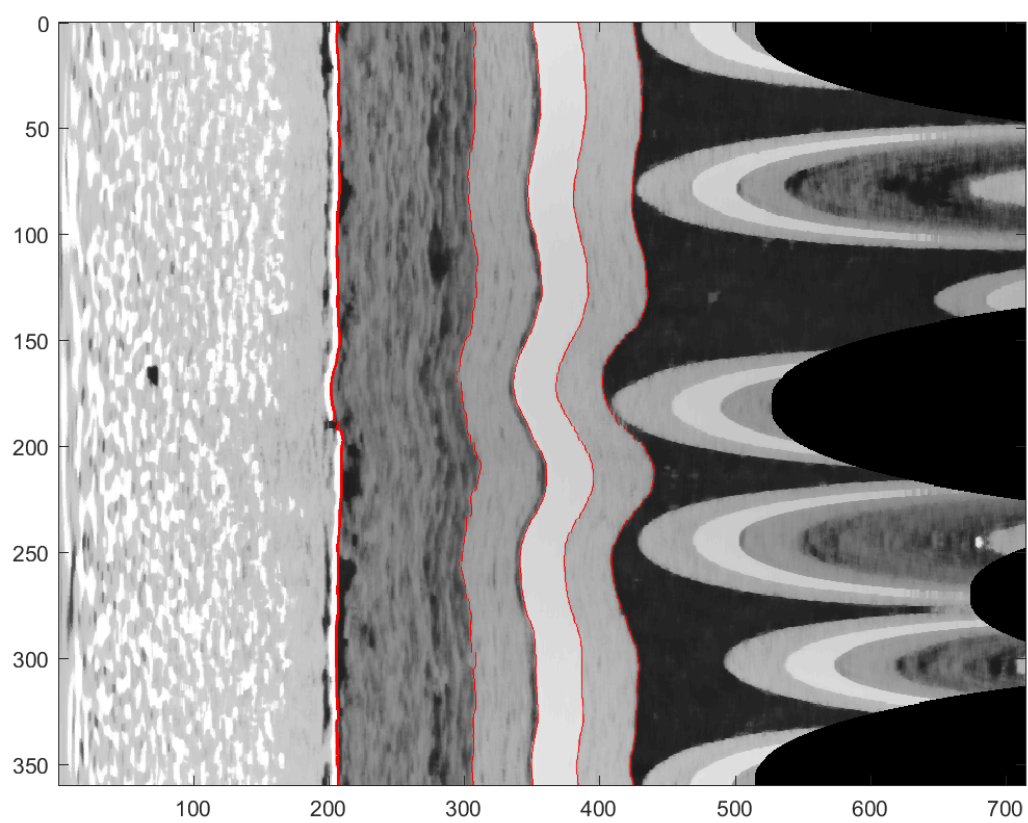
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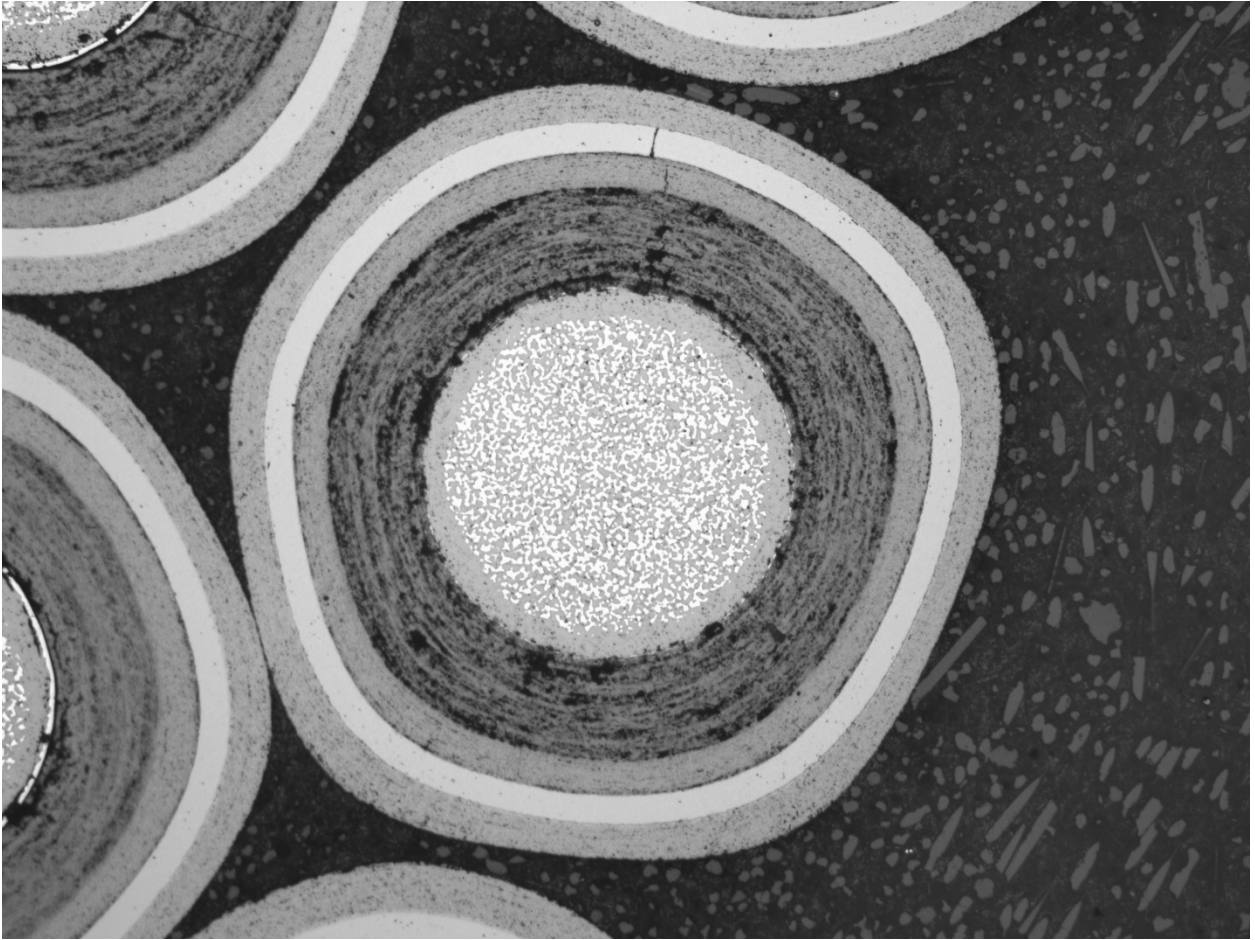


P16082301N277

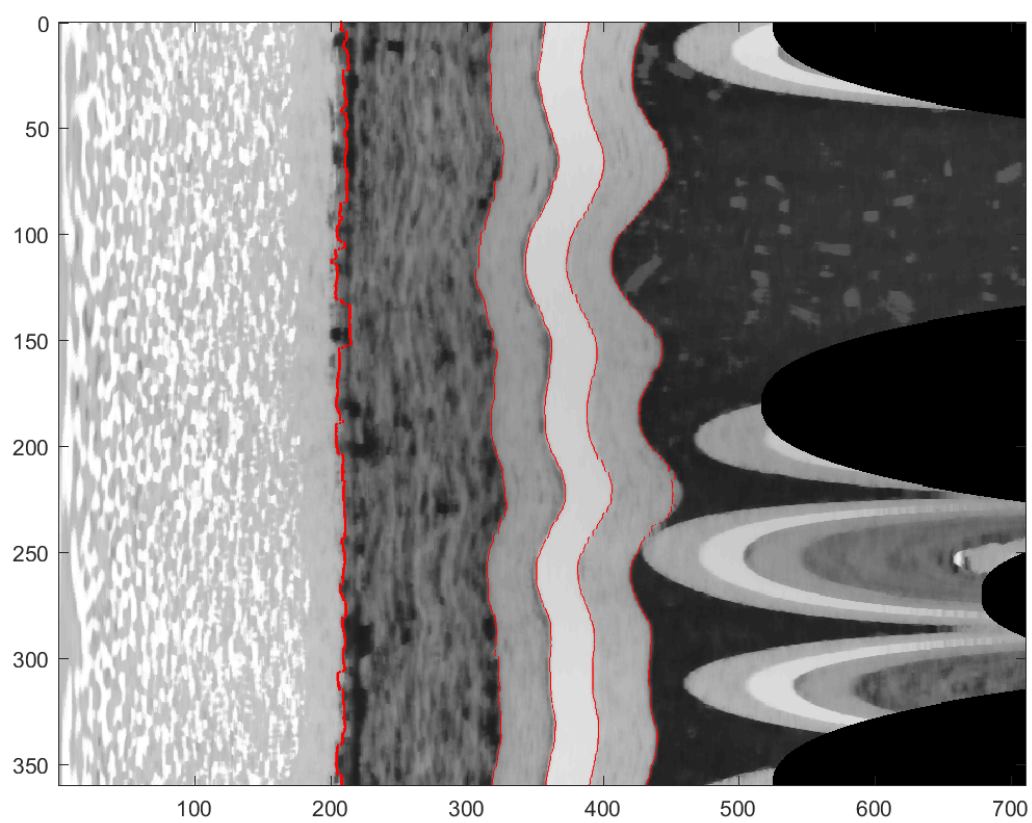


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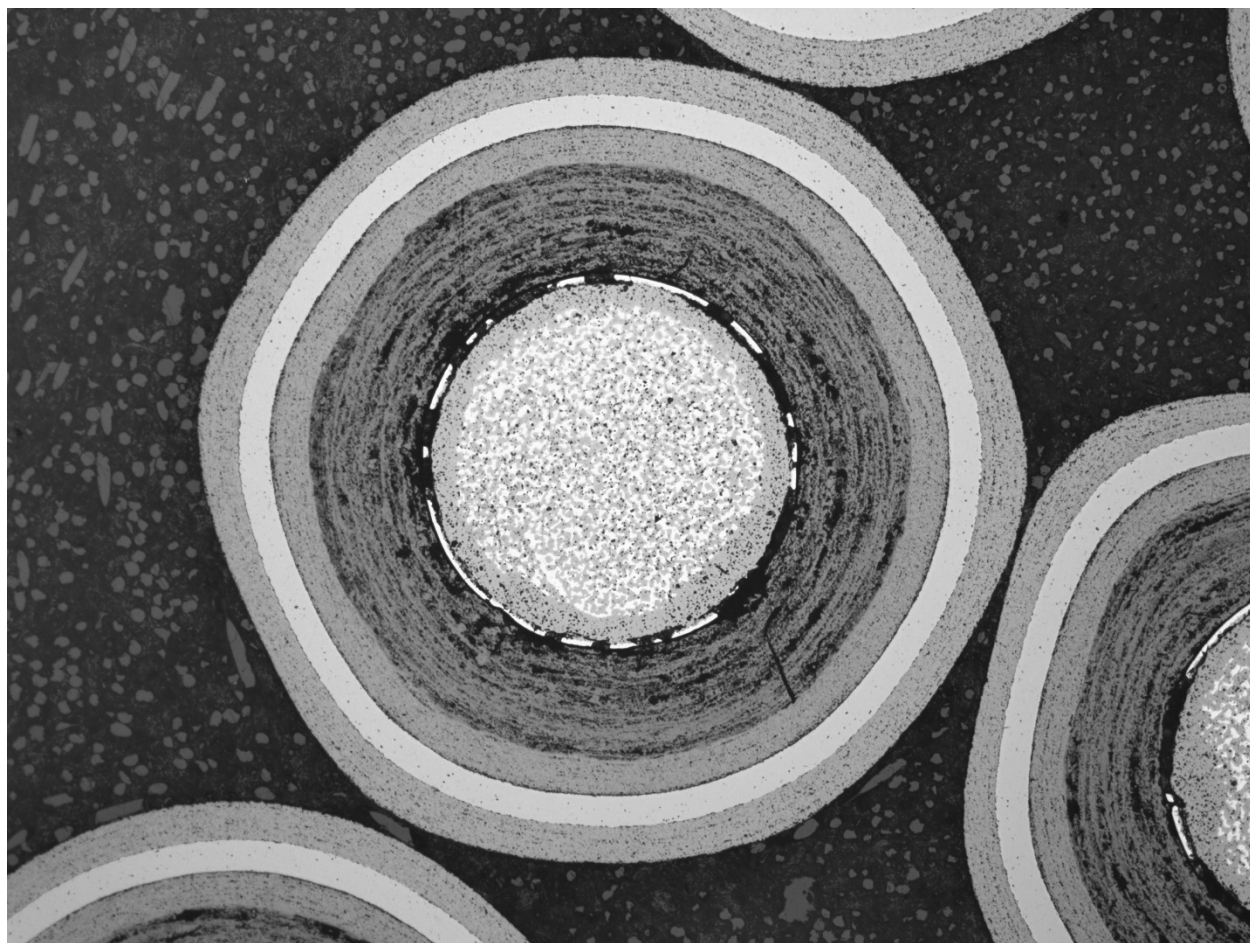




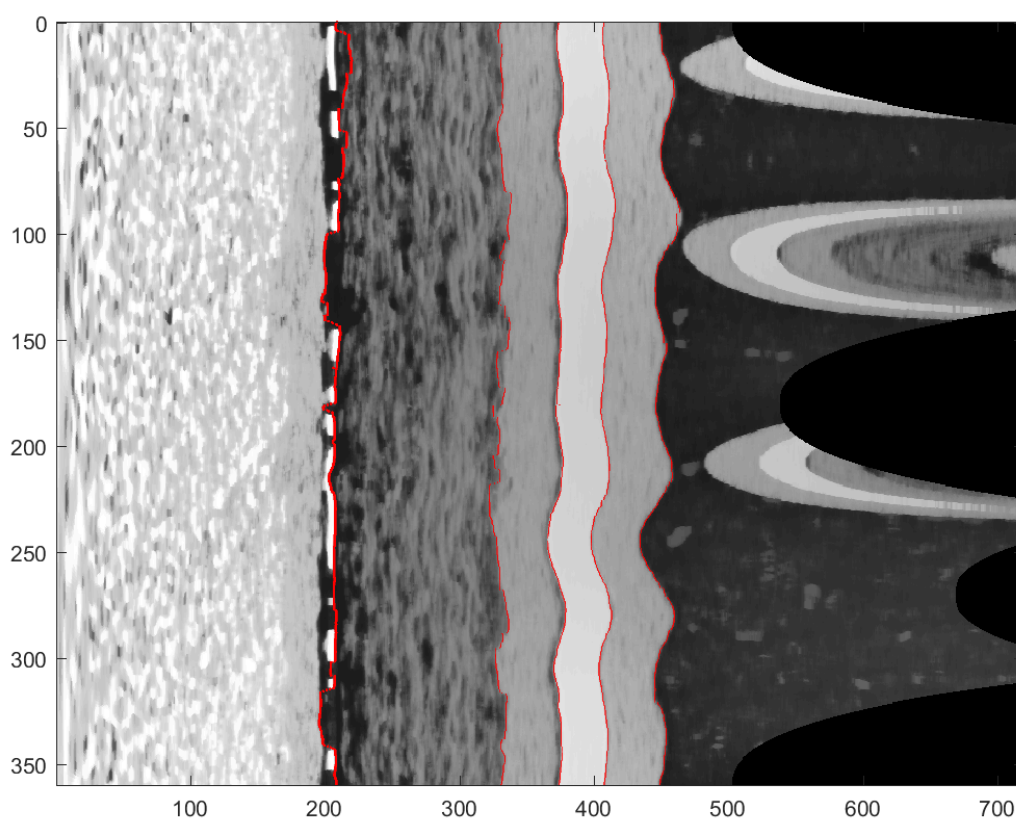
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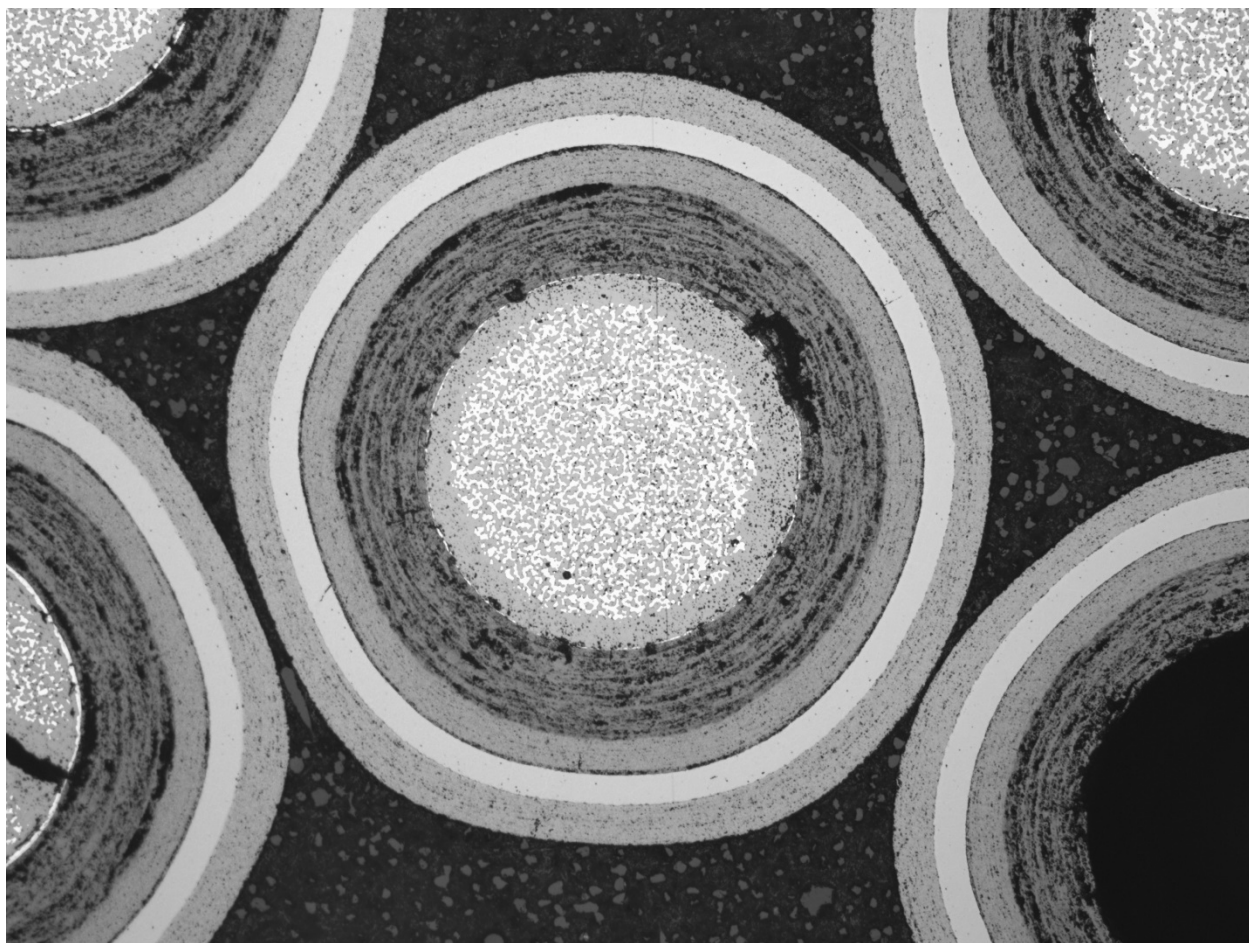
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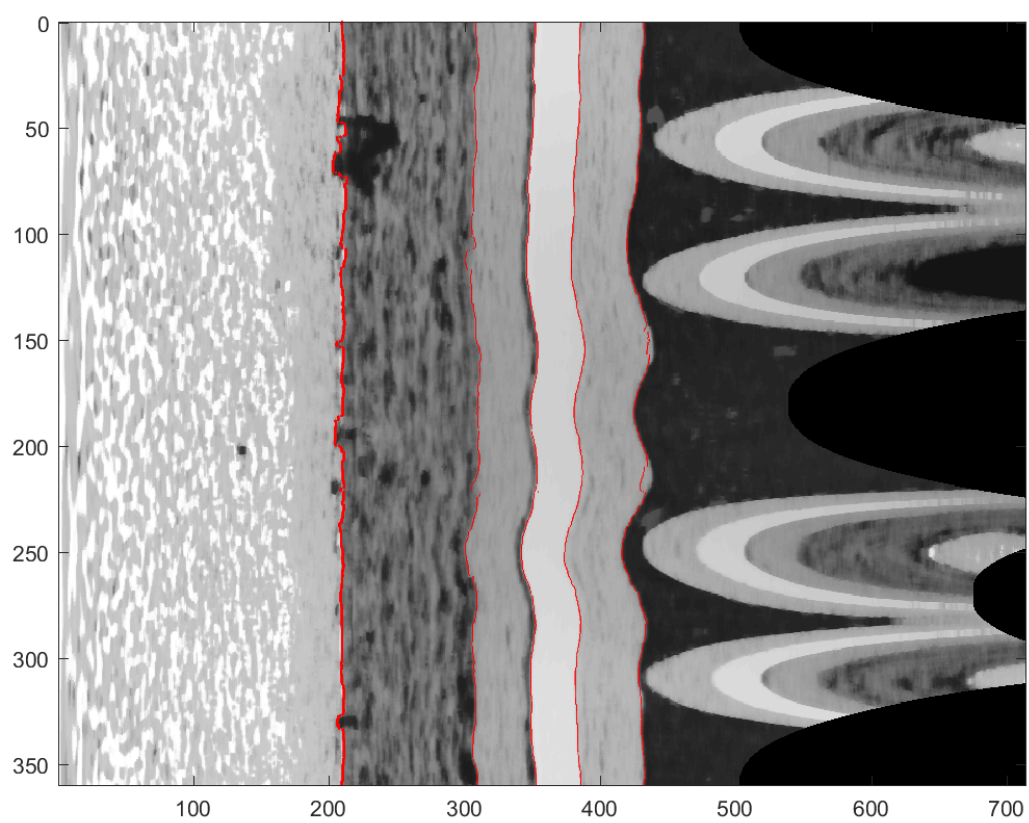
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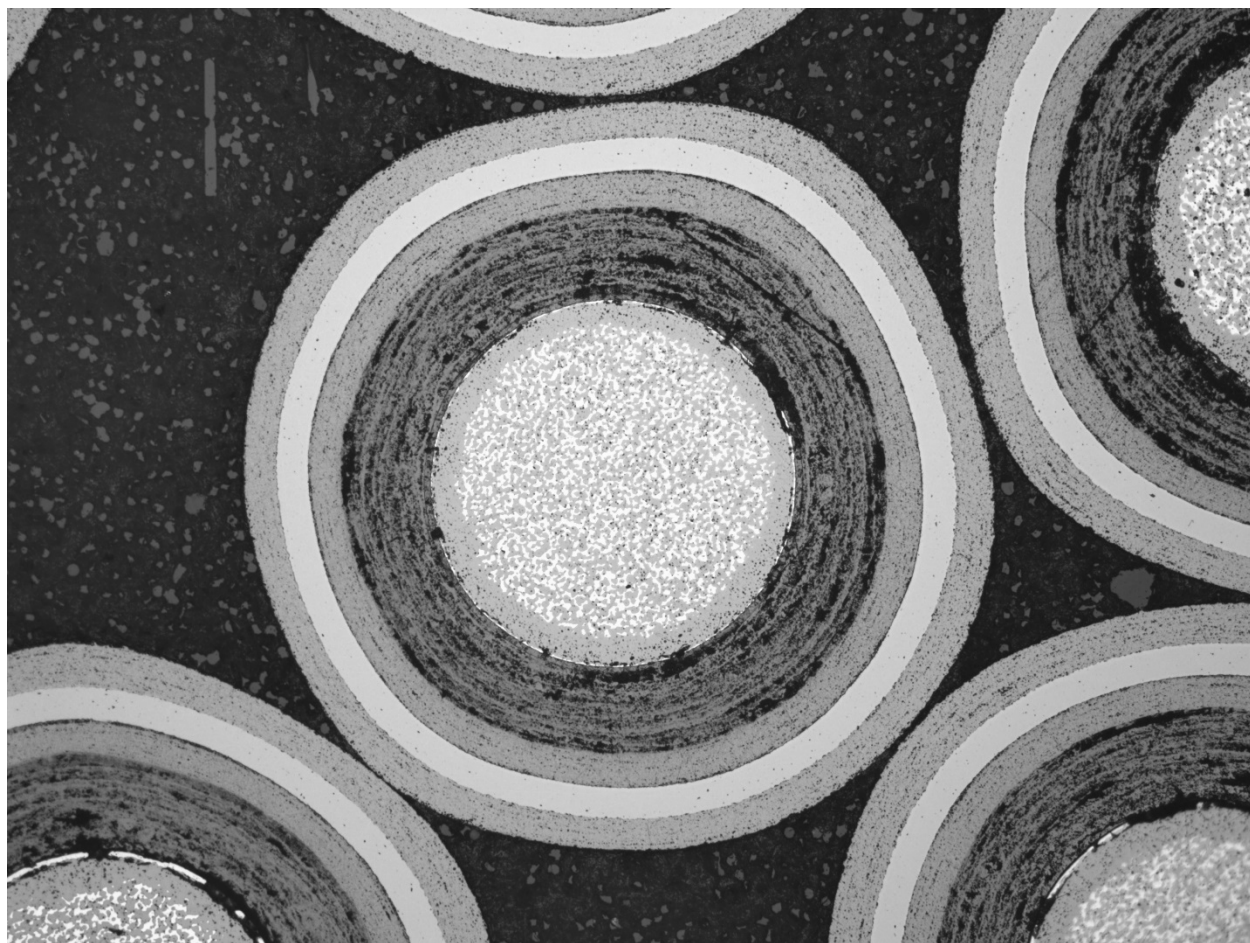


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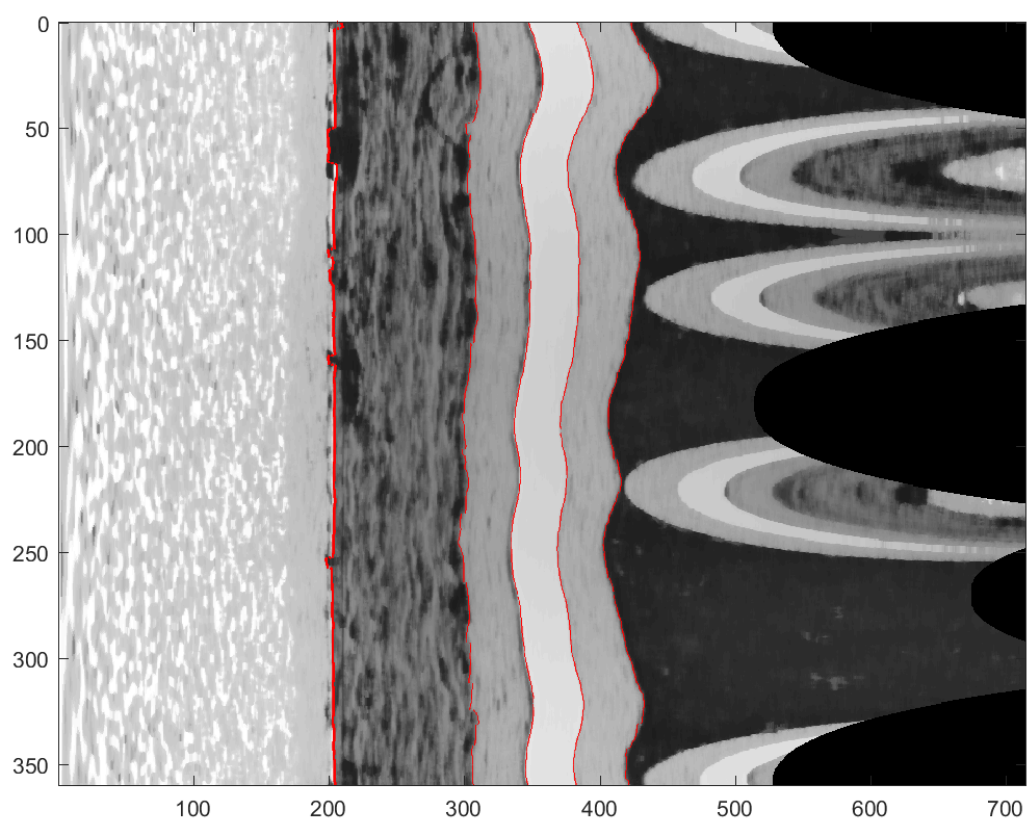


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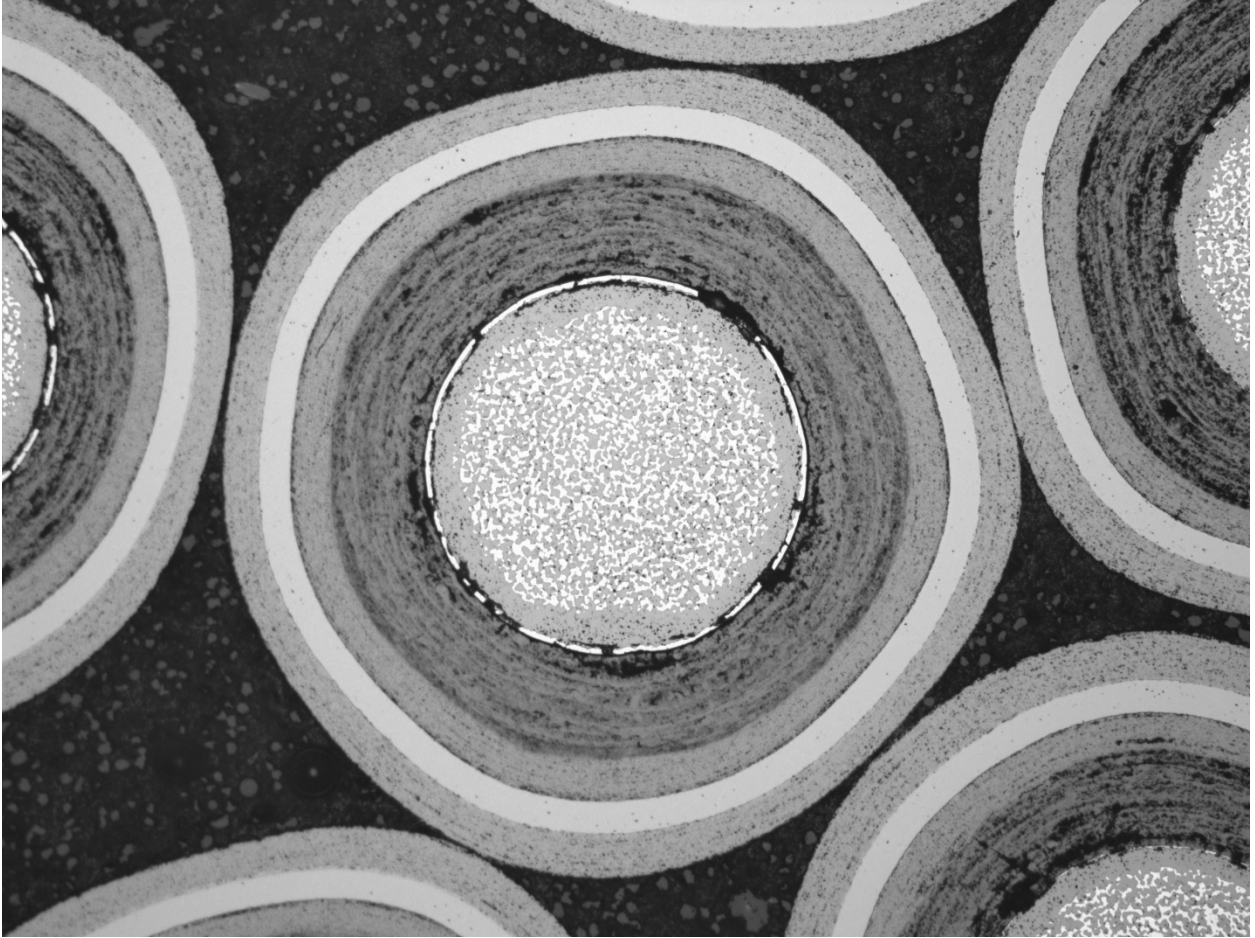




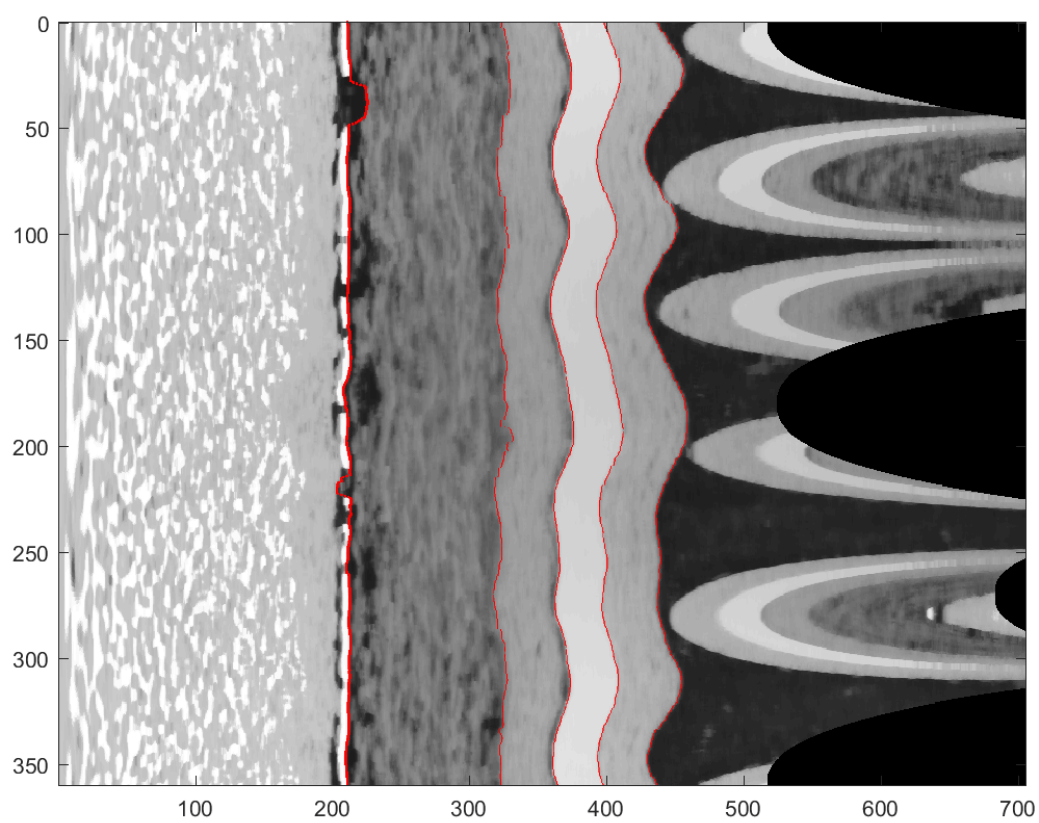
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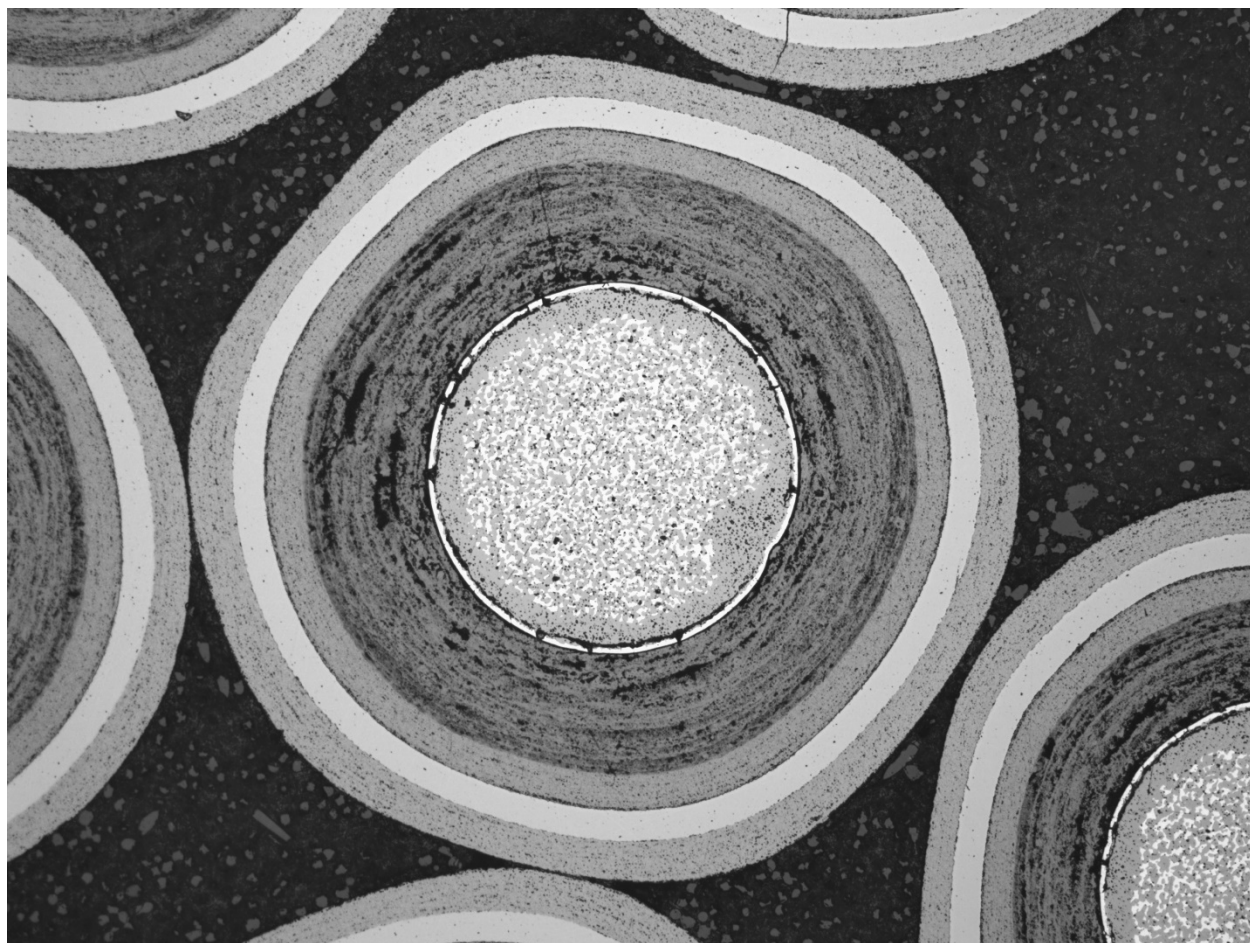
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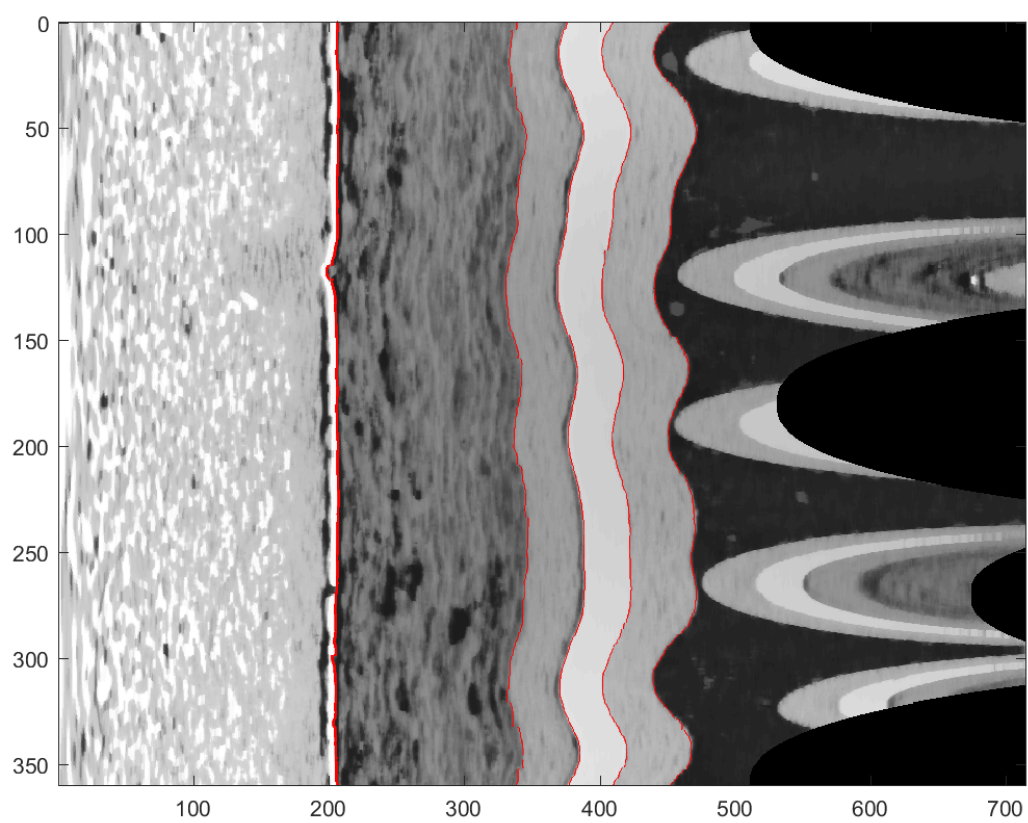
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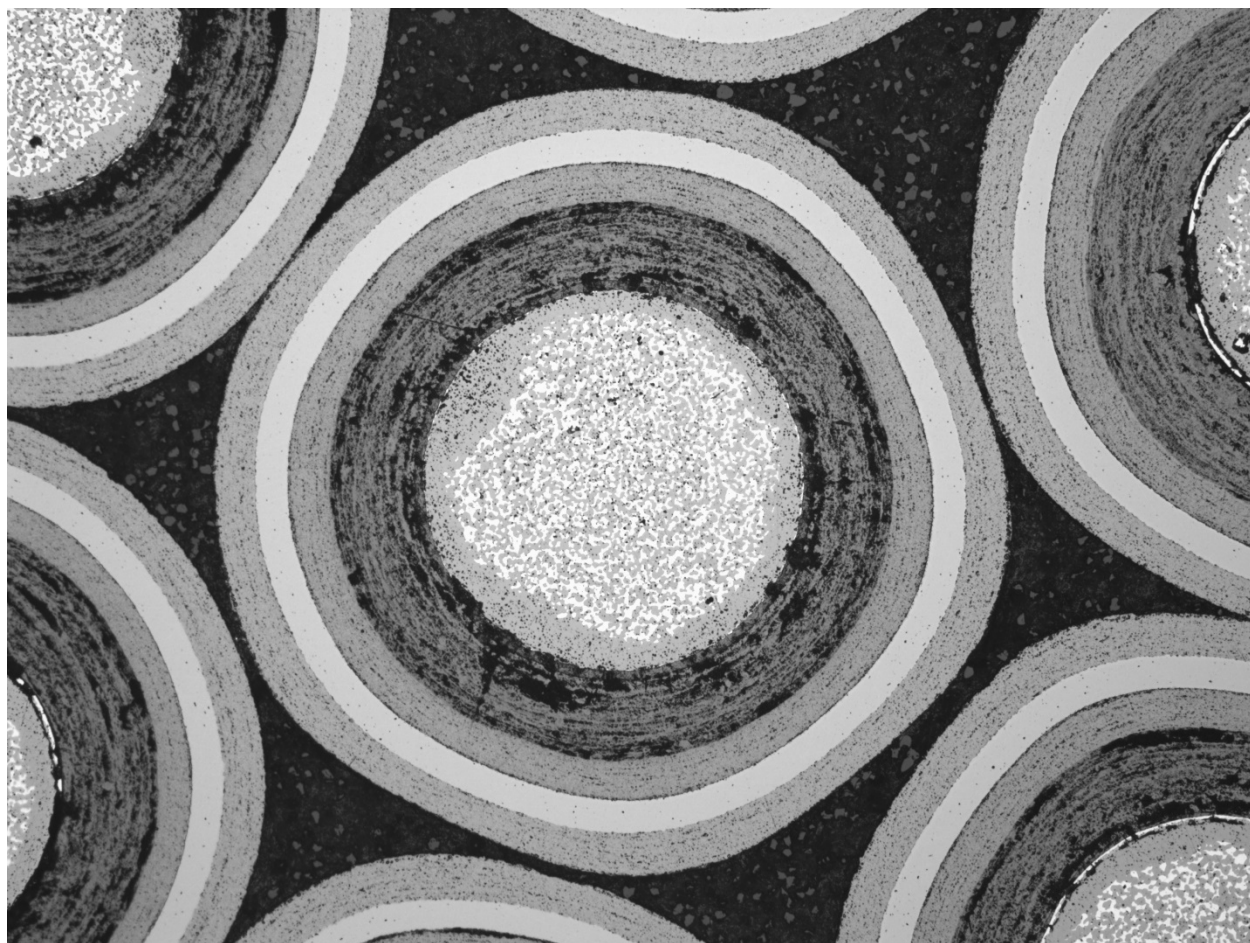


P16082301N284

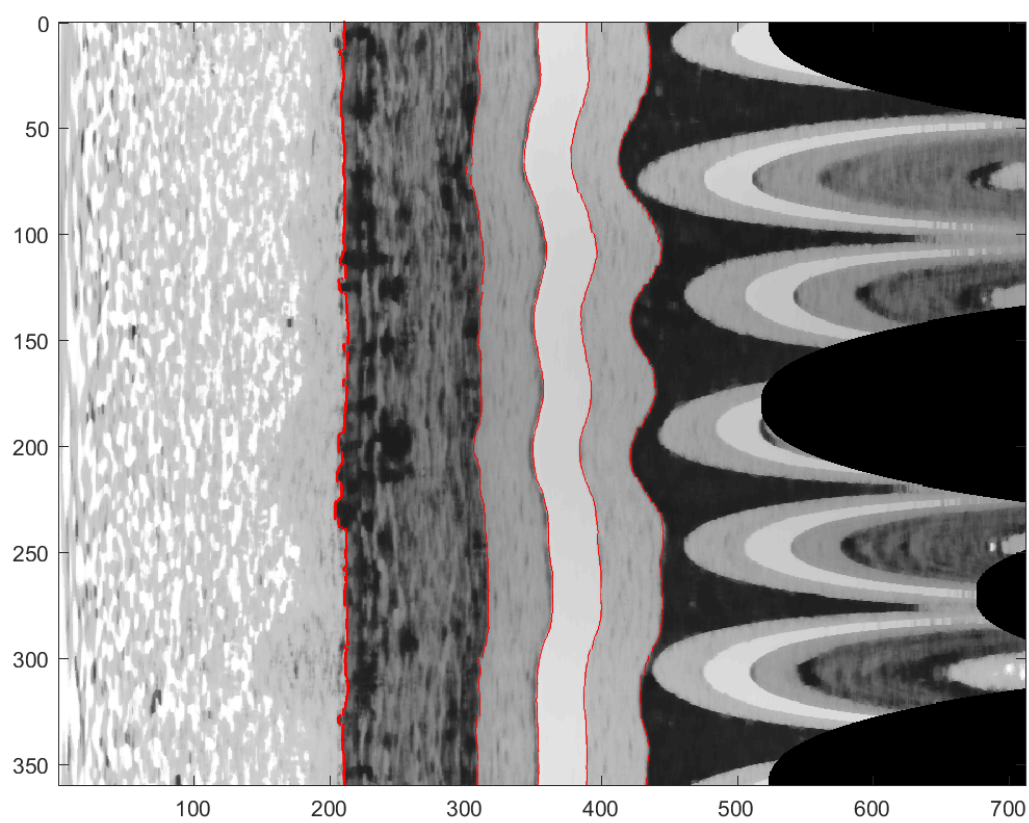


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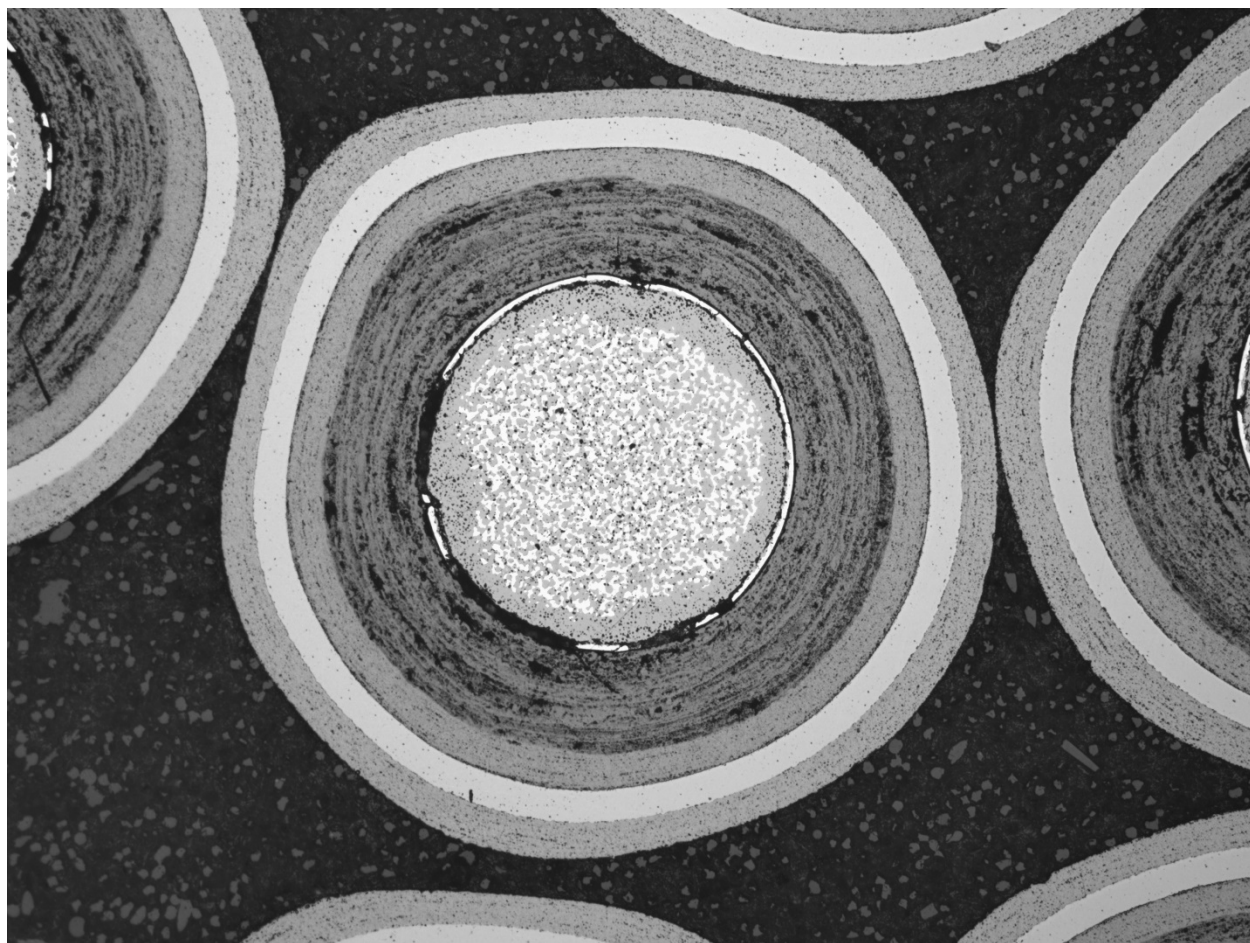




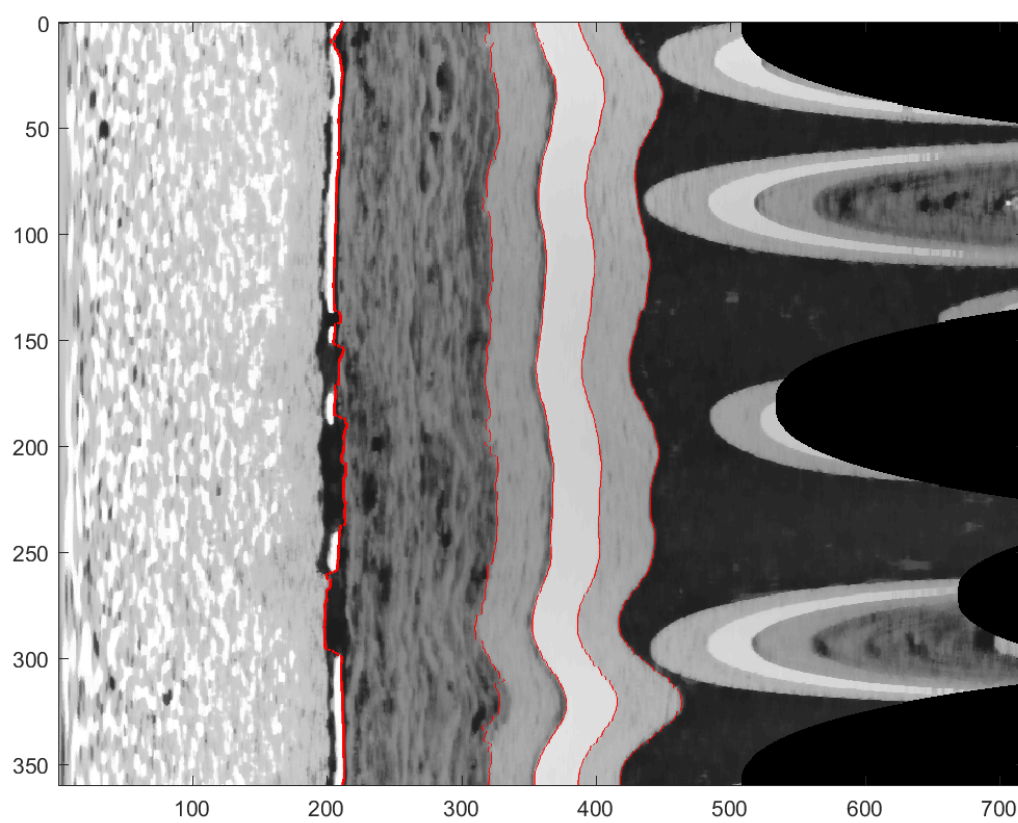
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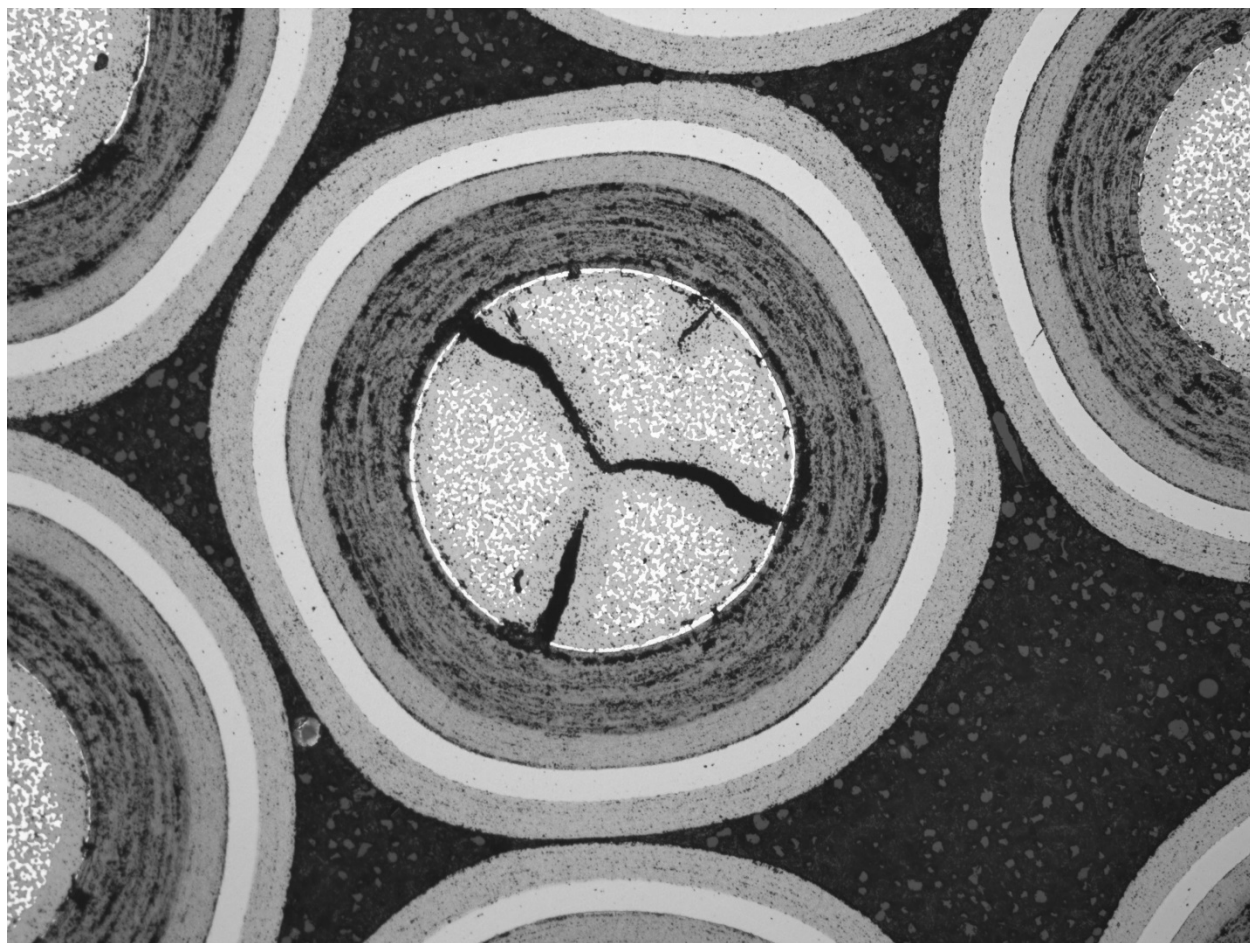
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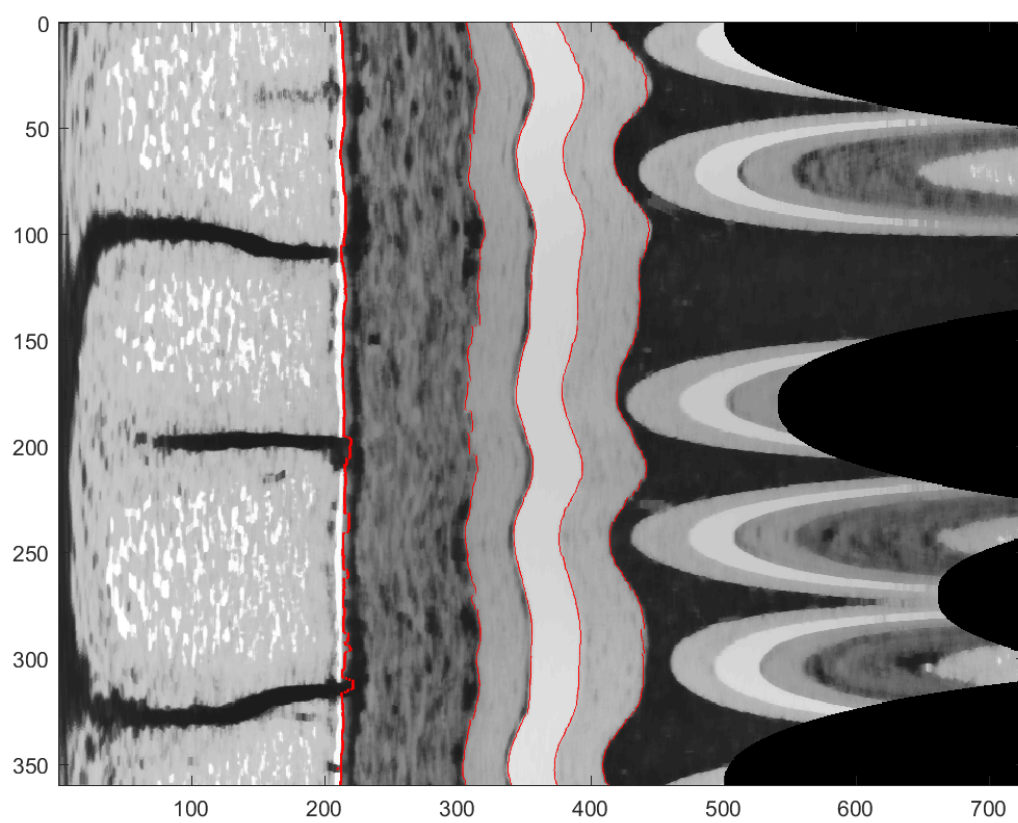
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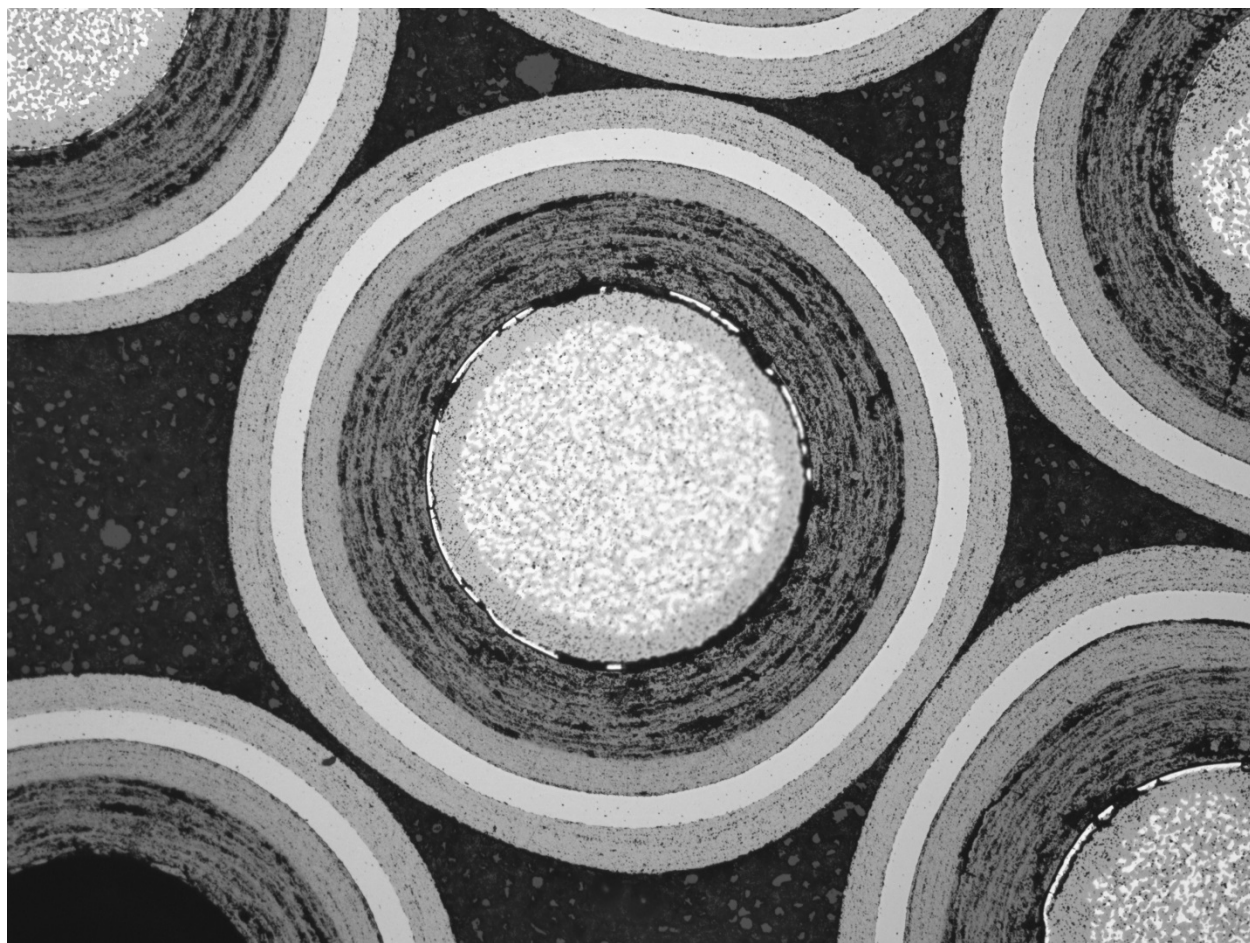


P16082301N288

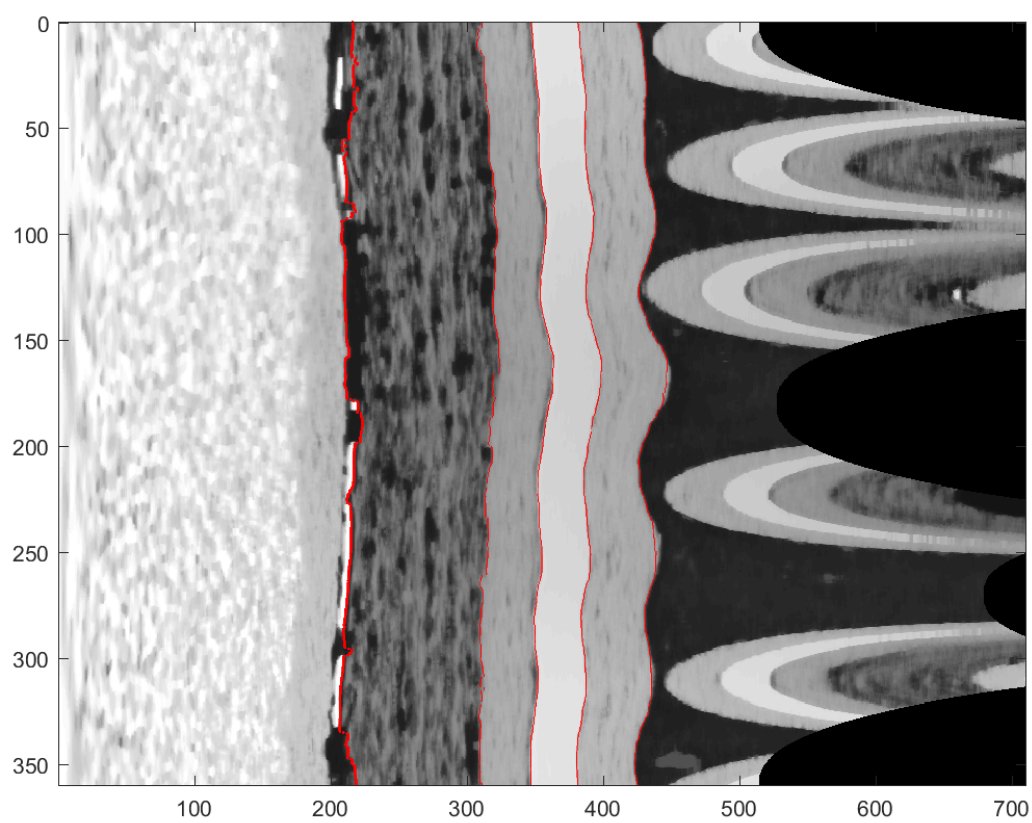


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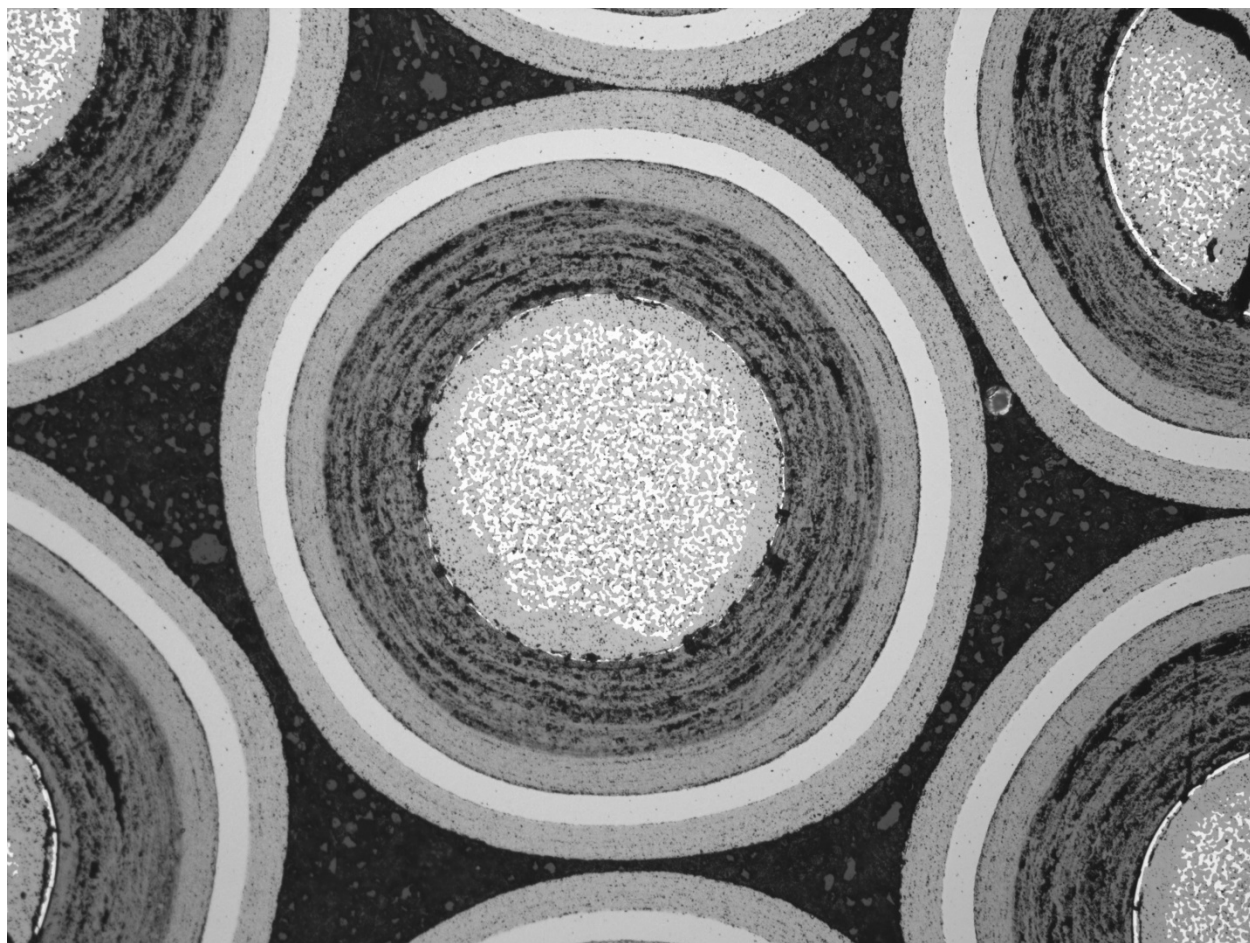




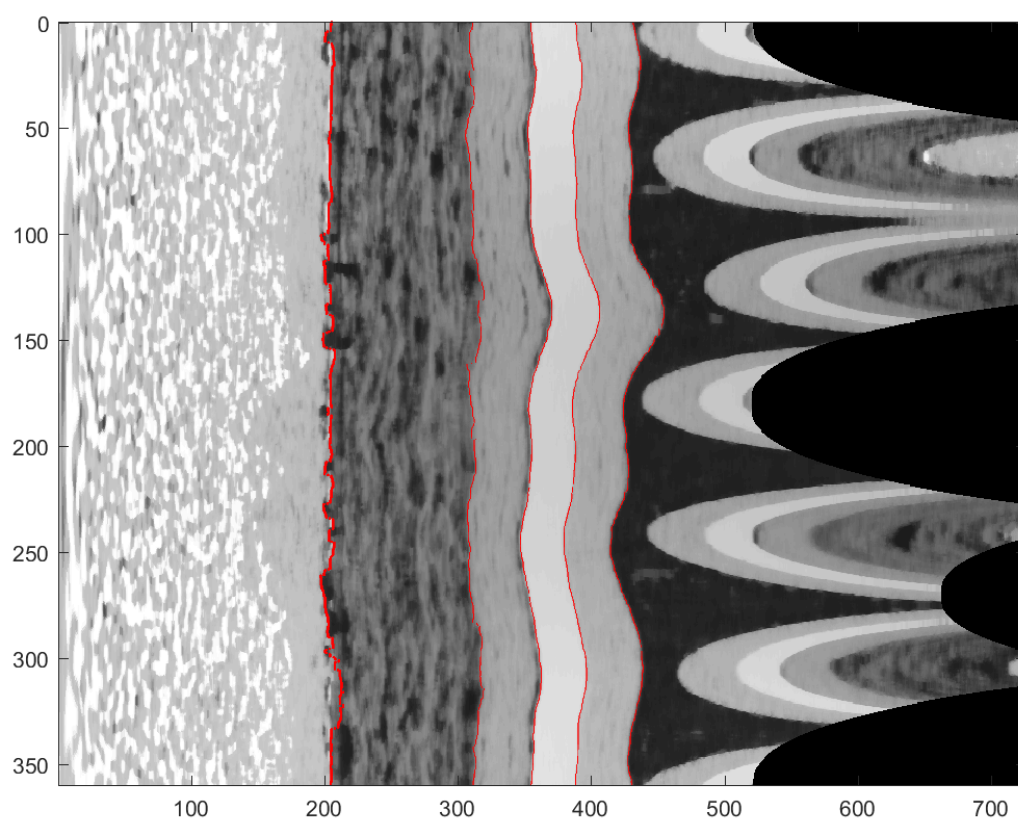
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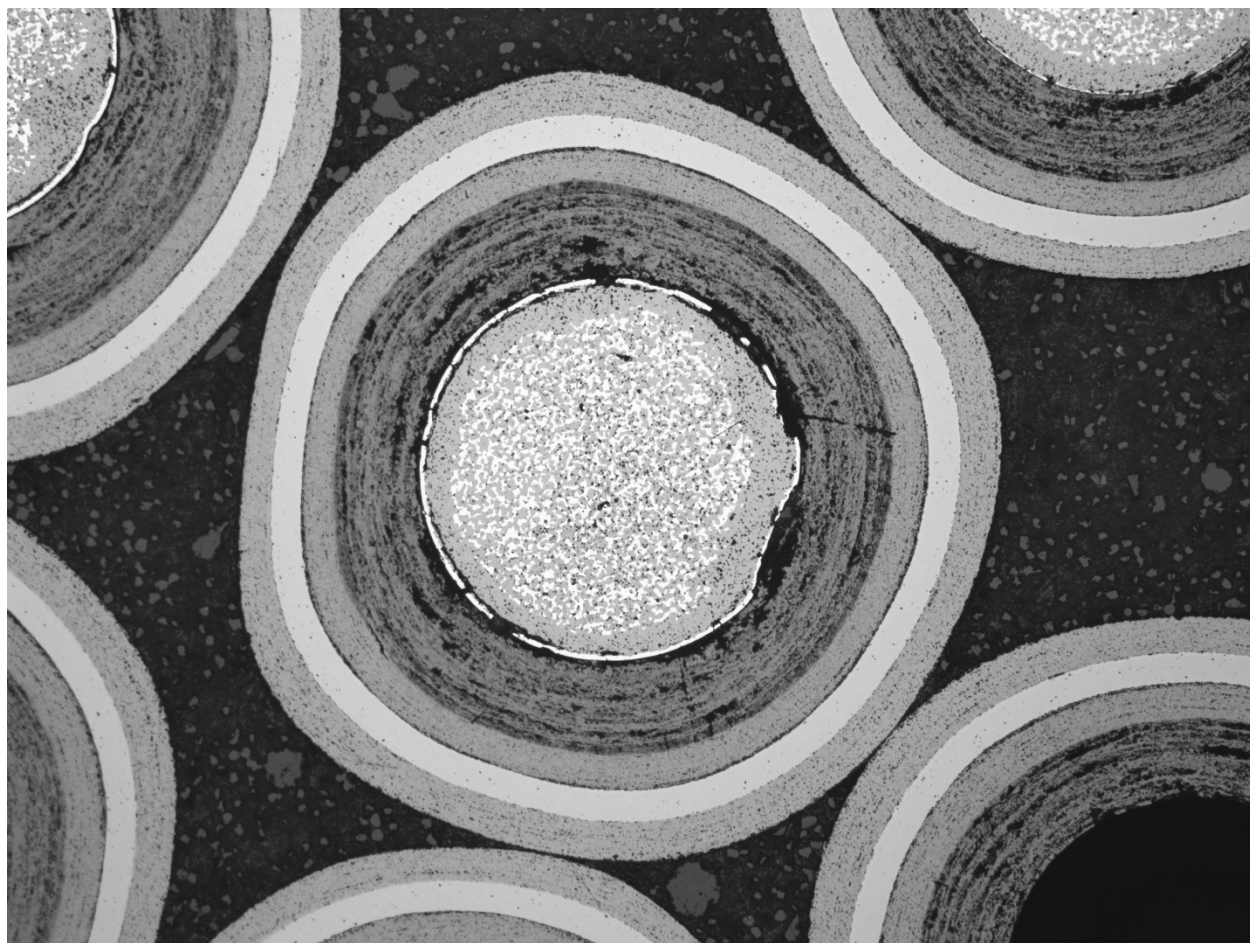
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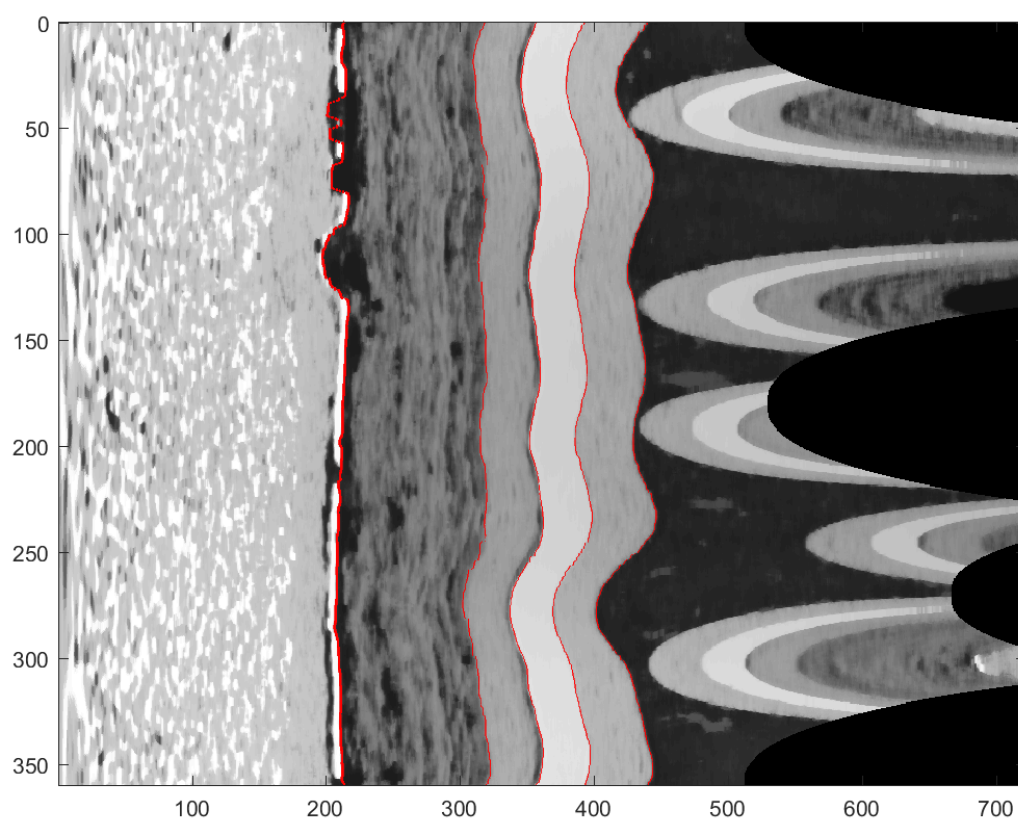
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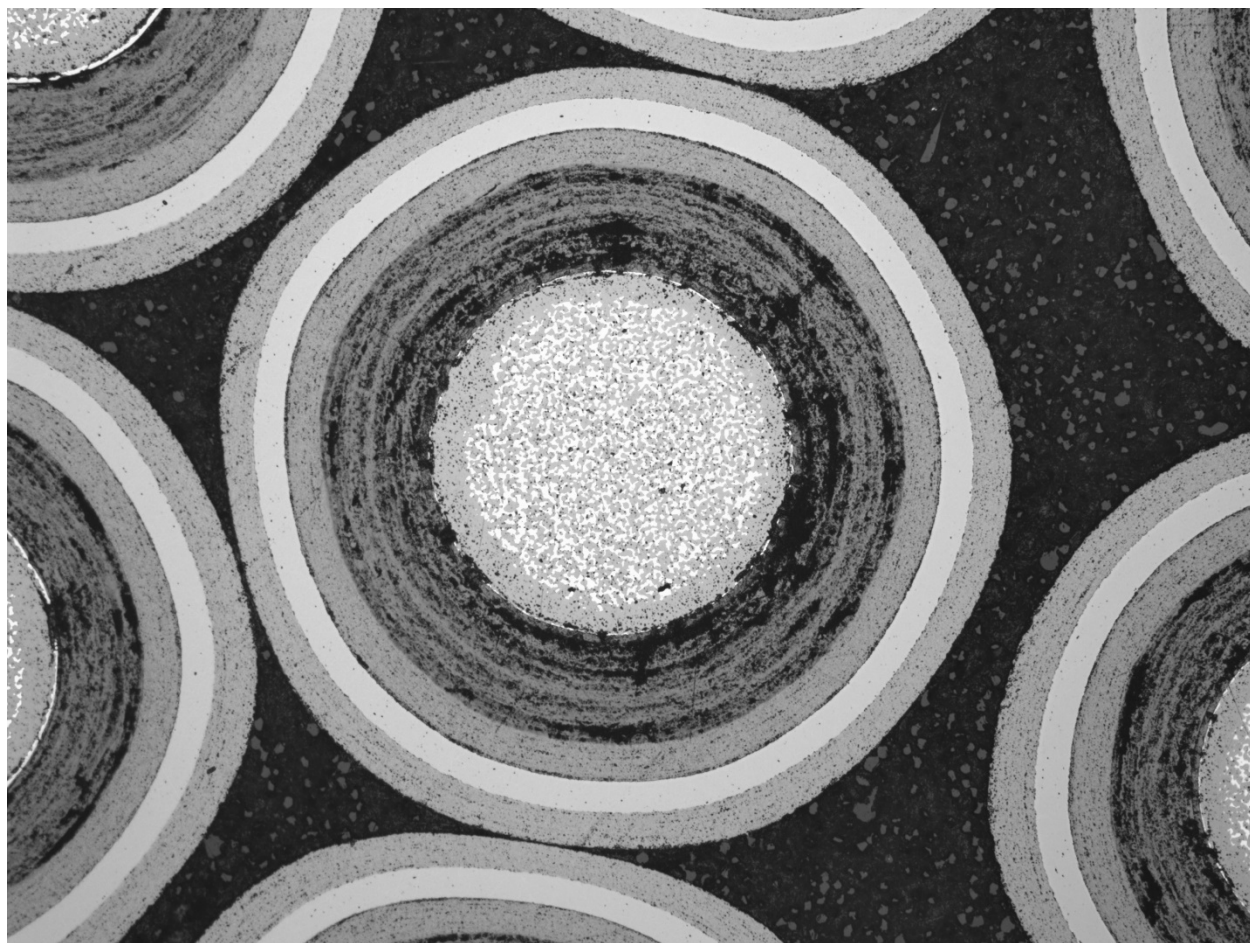


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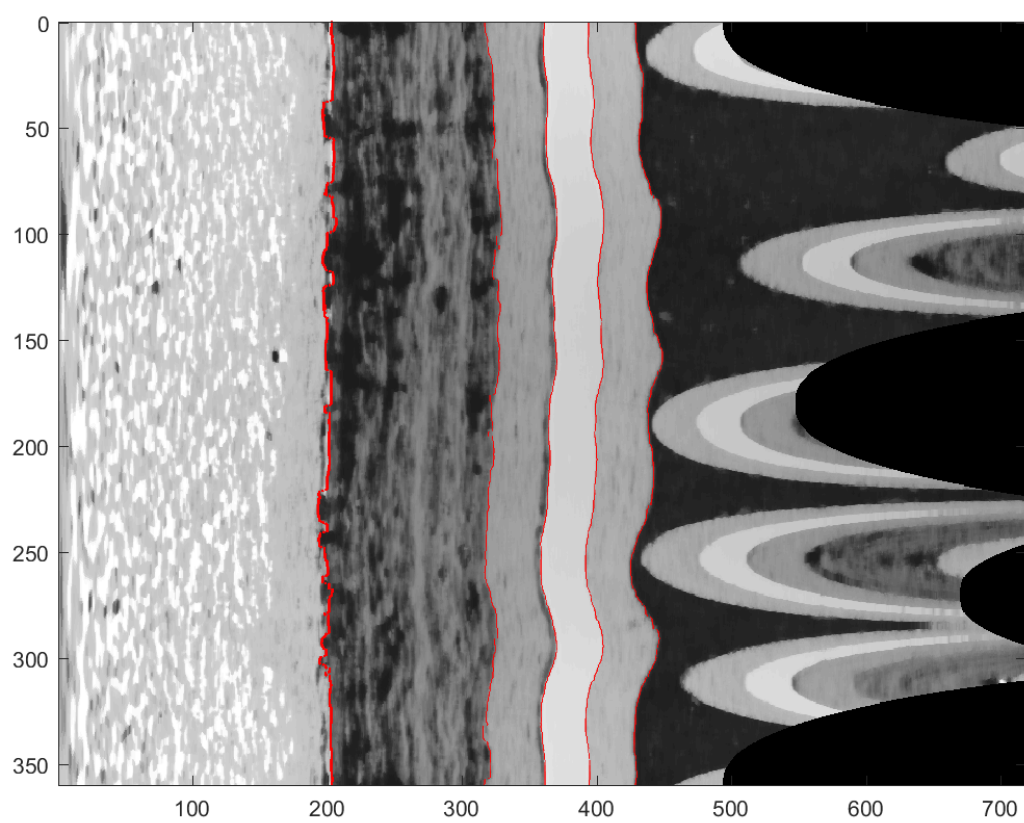


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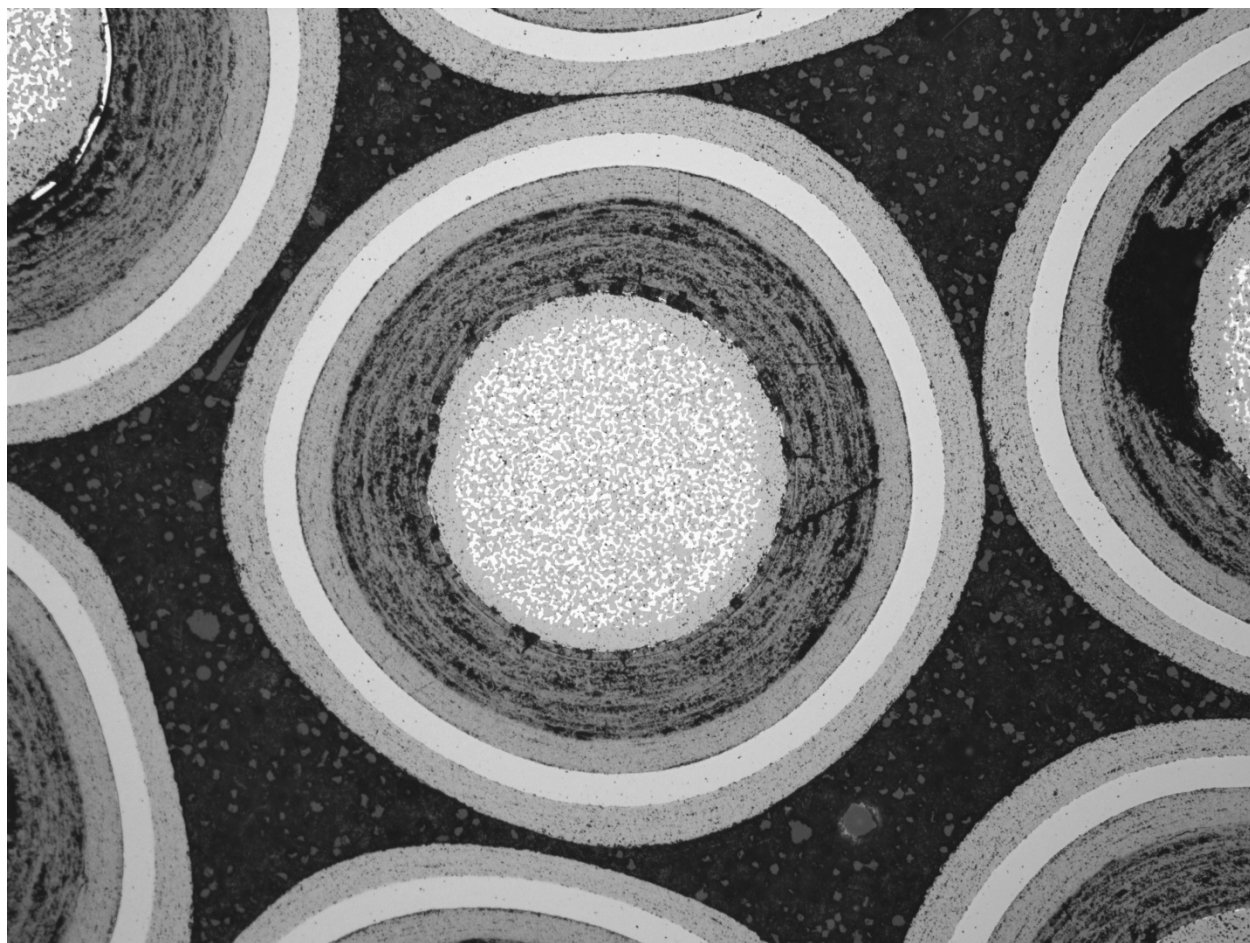




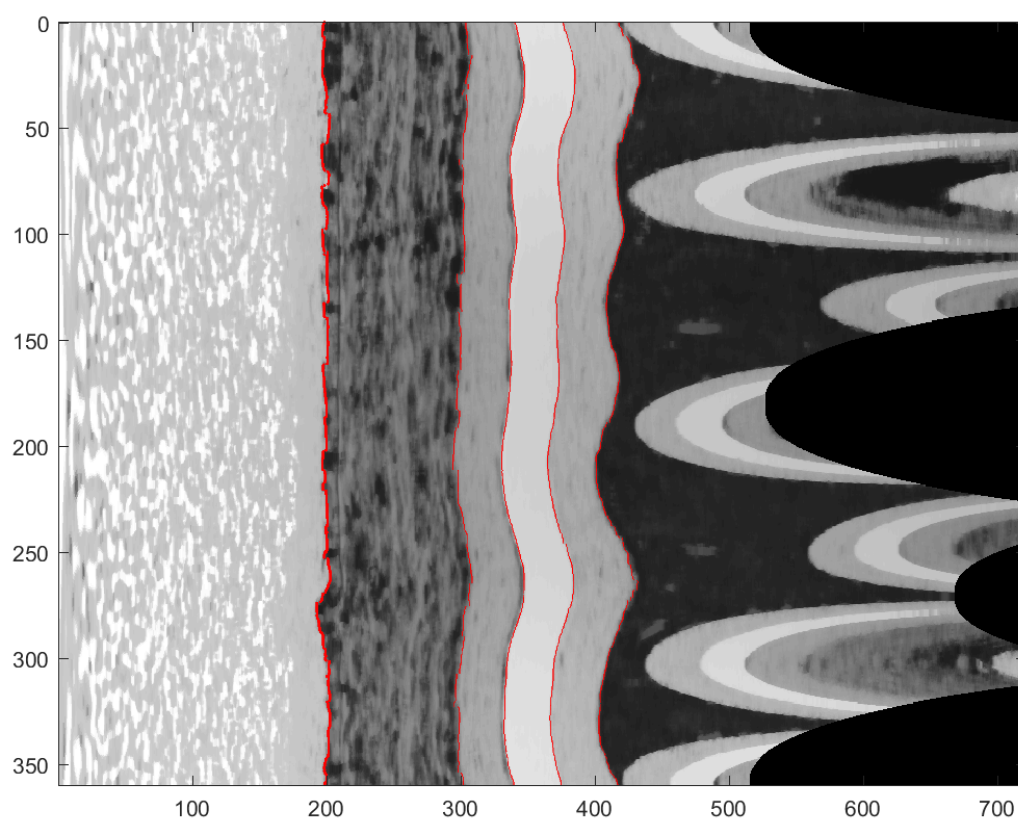
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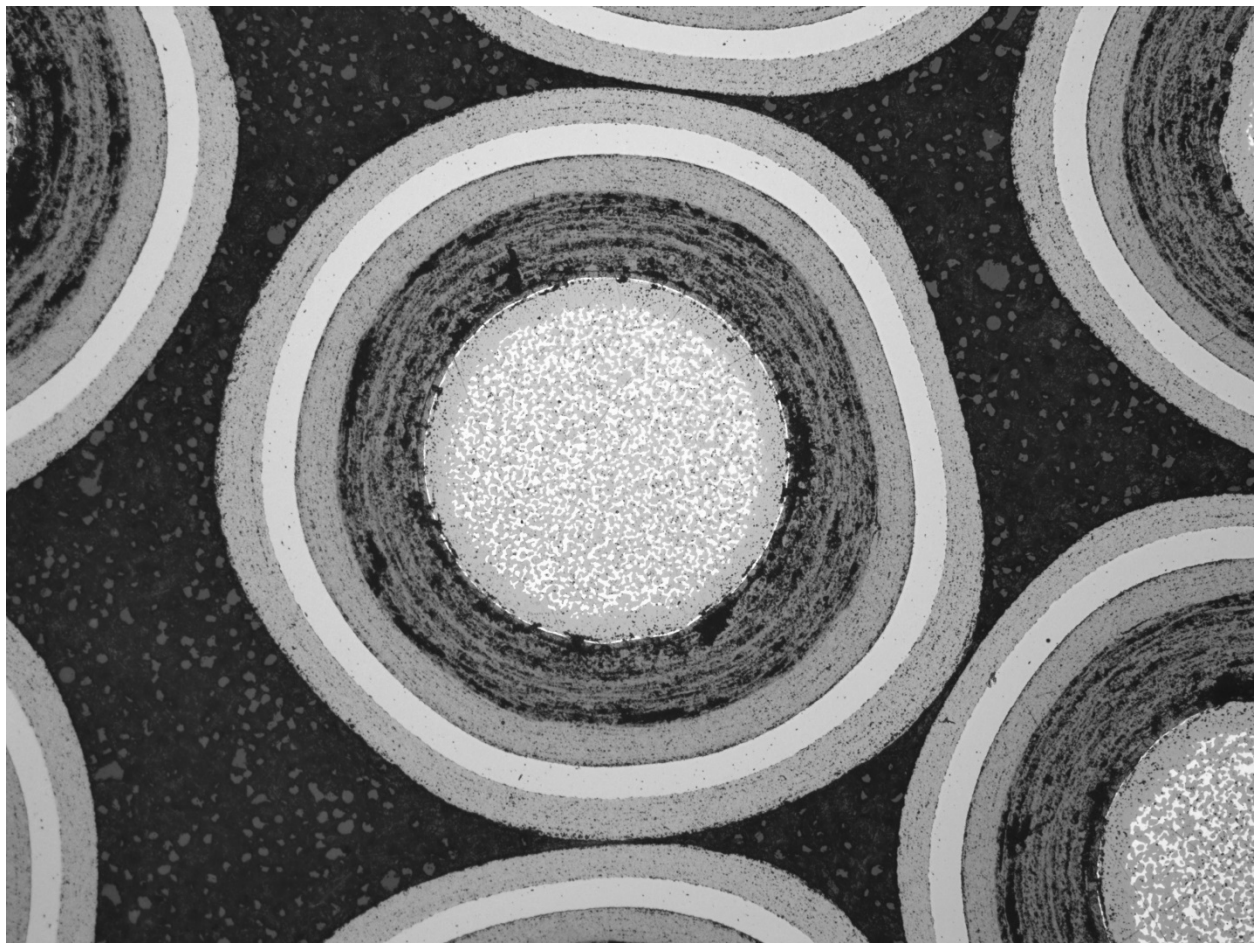
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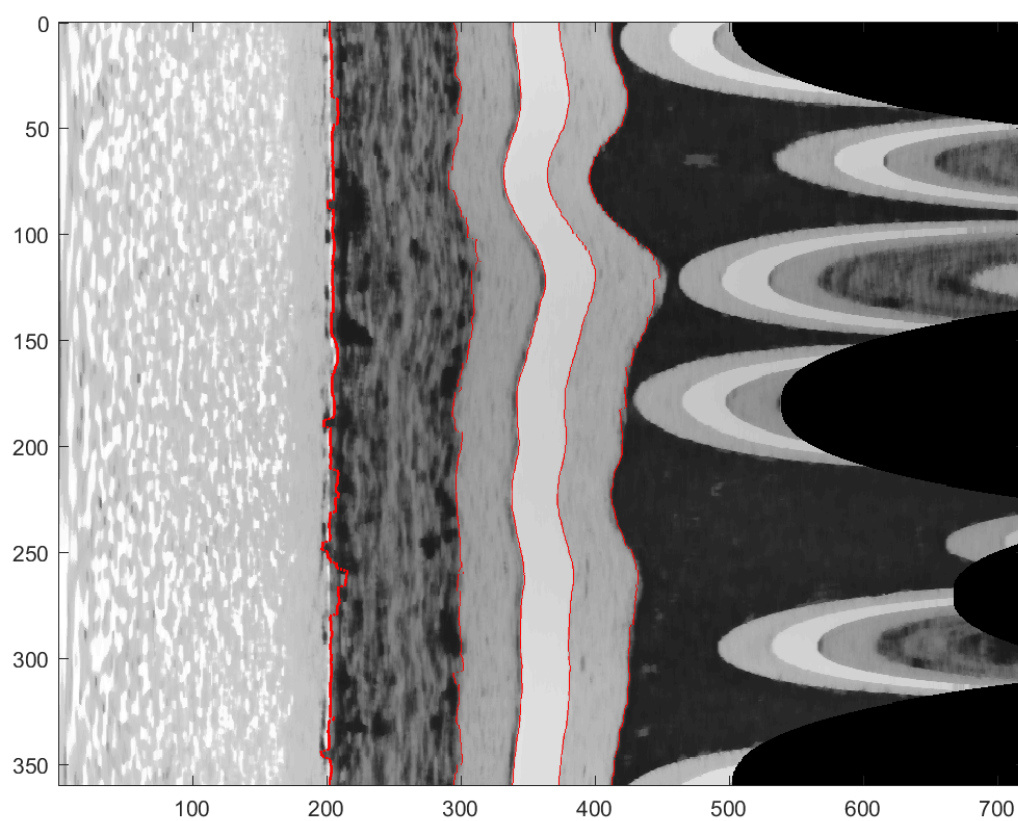
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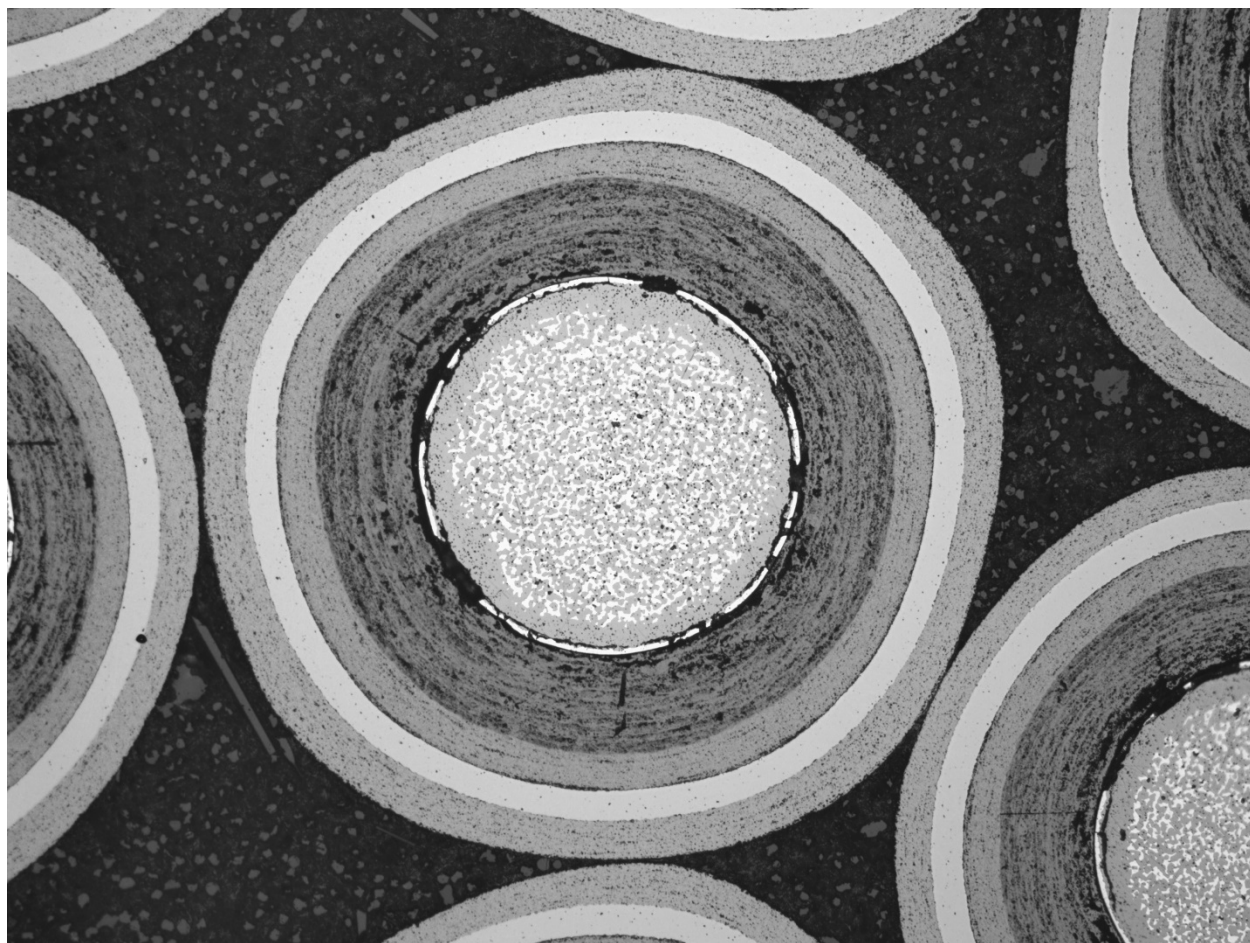


P16082301N300

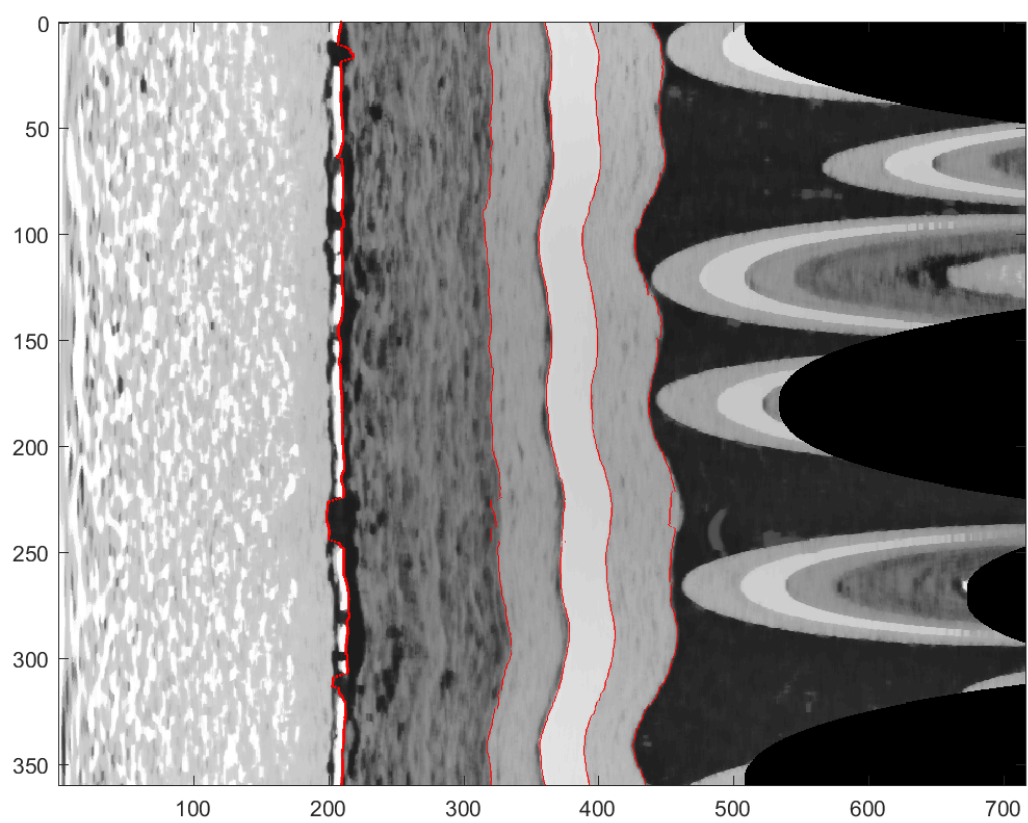


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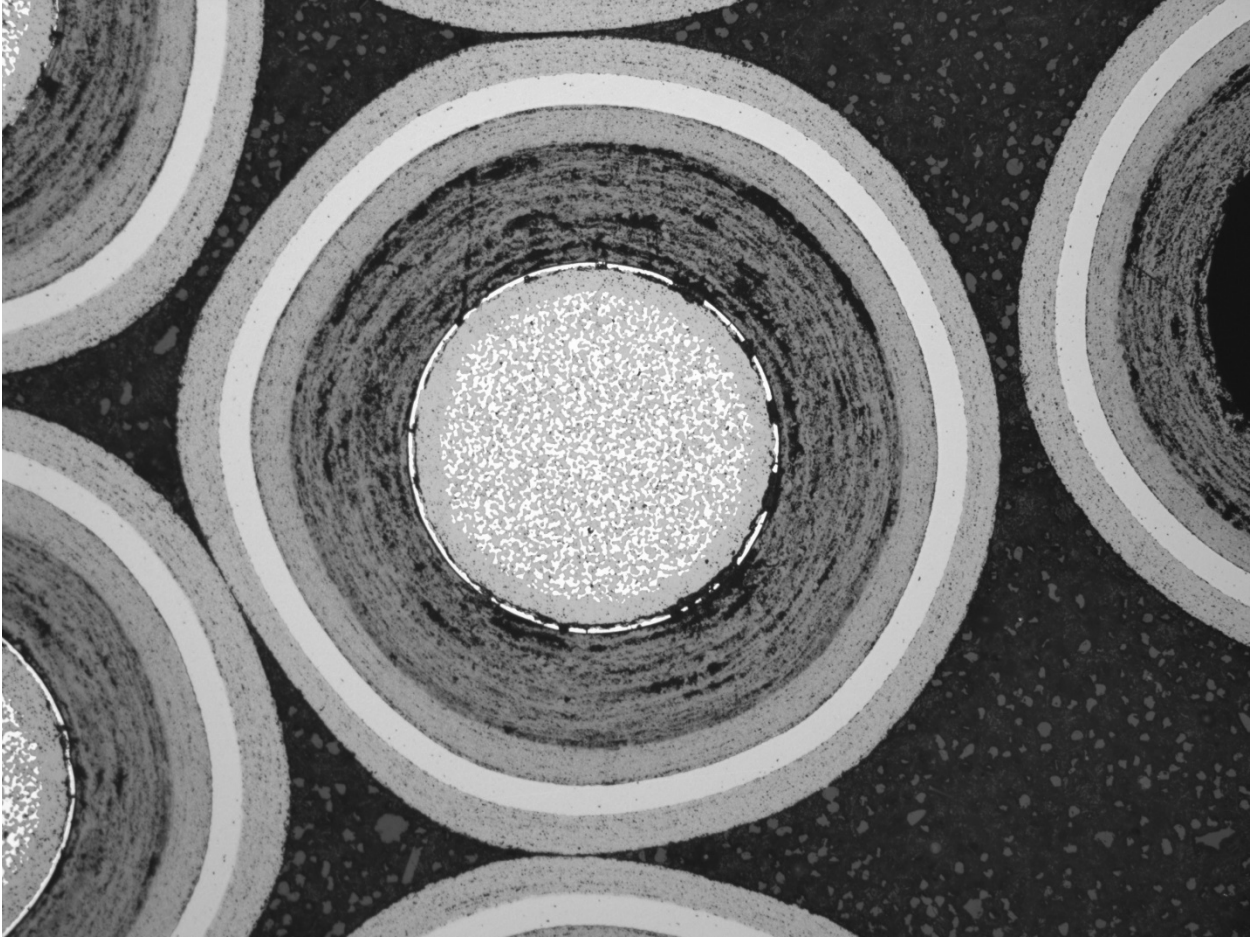




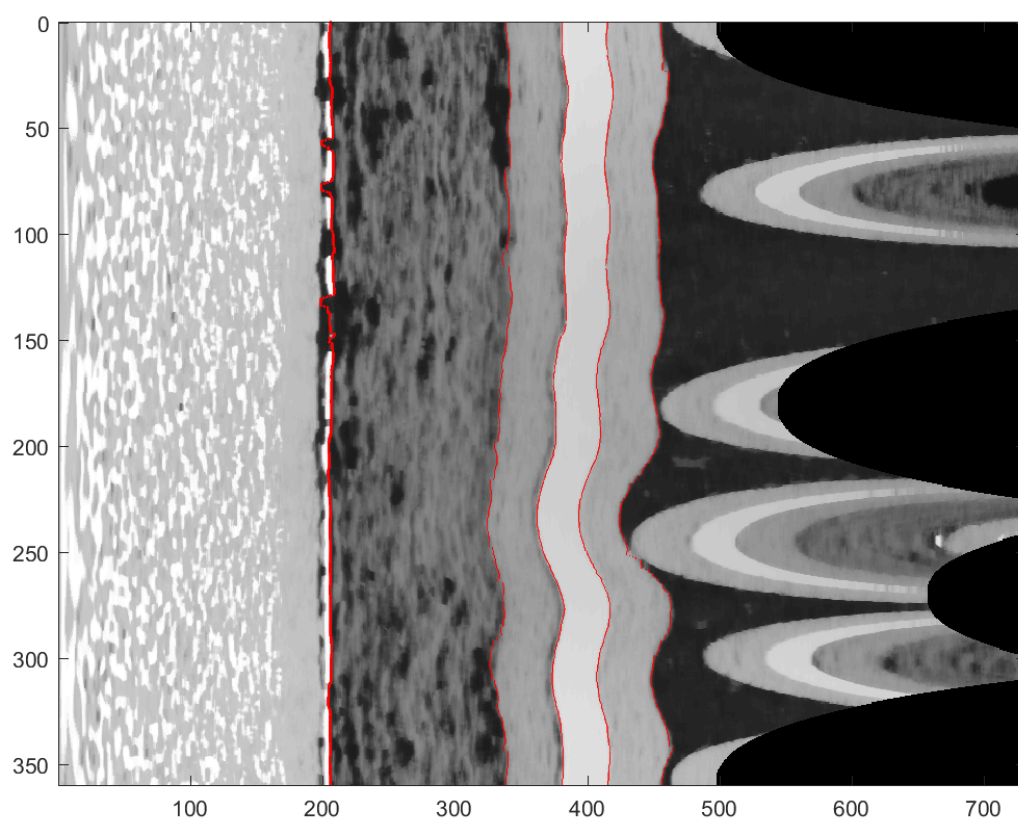
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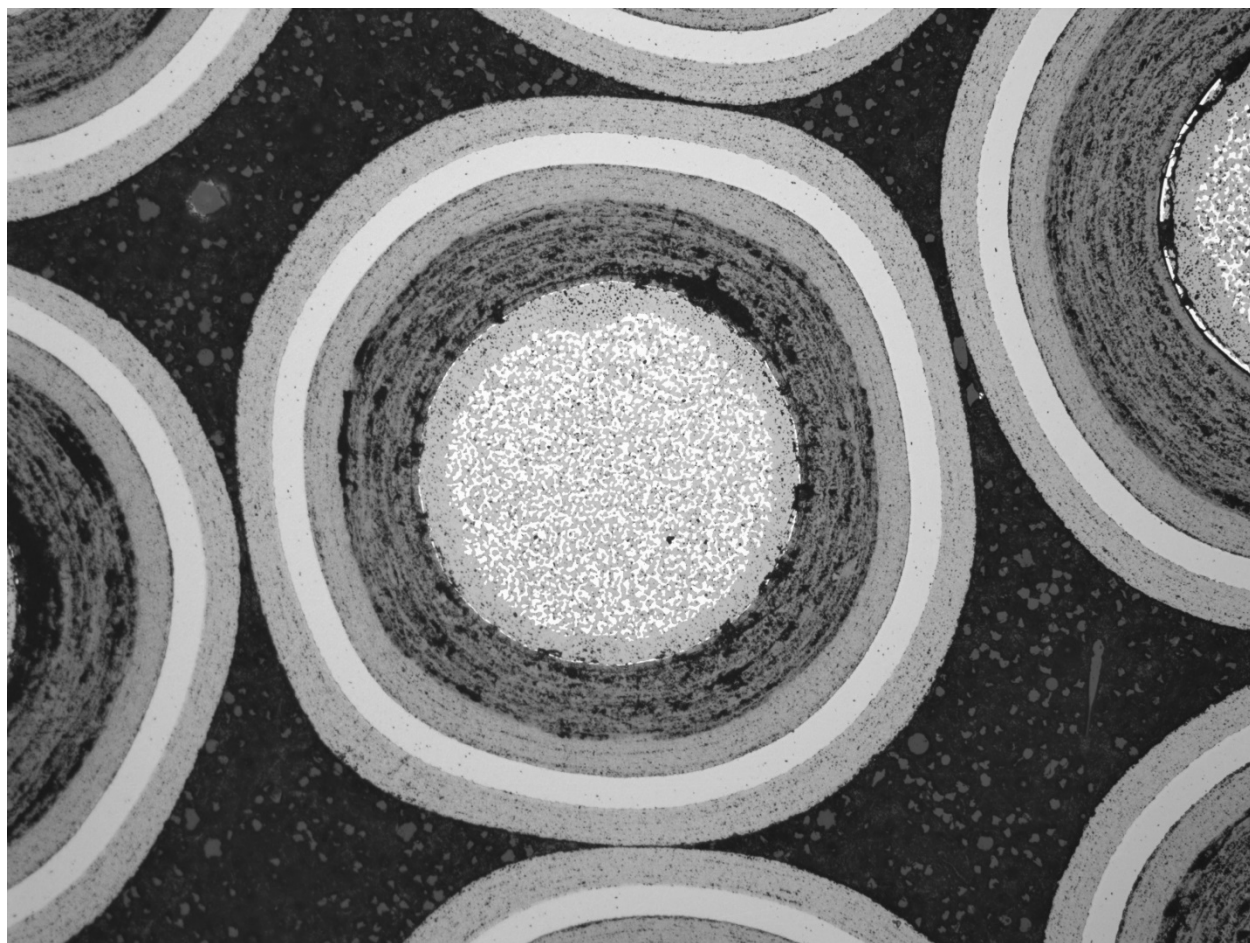
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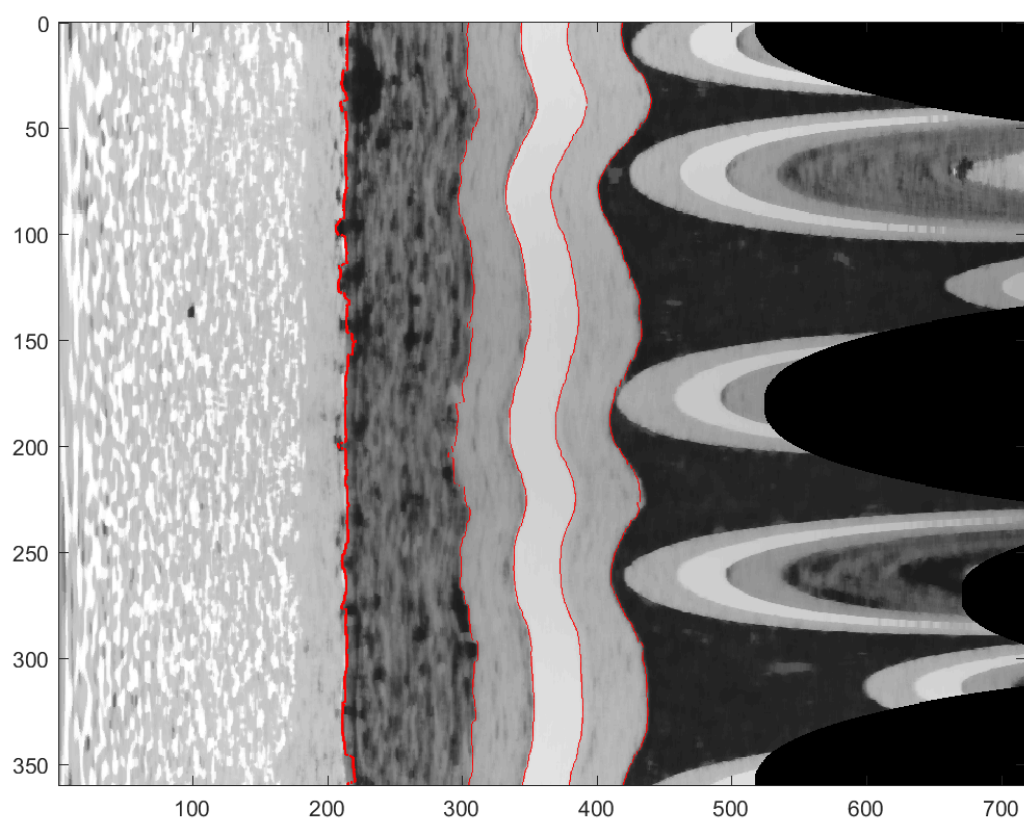
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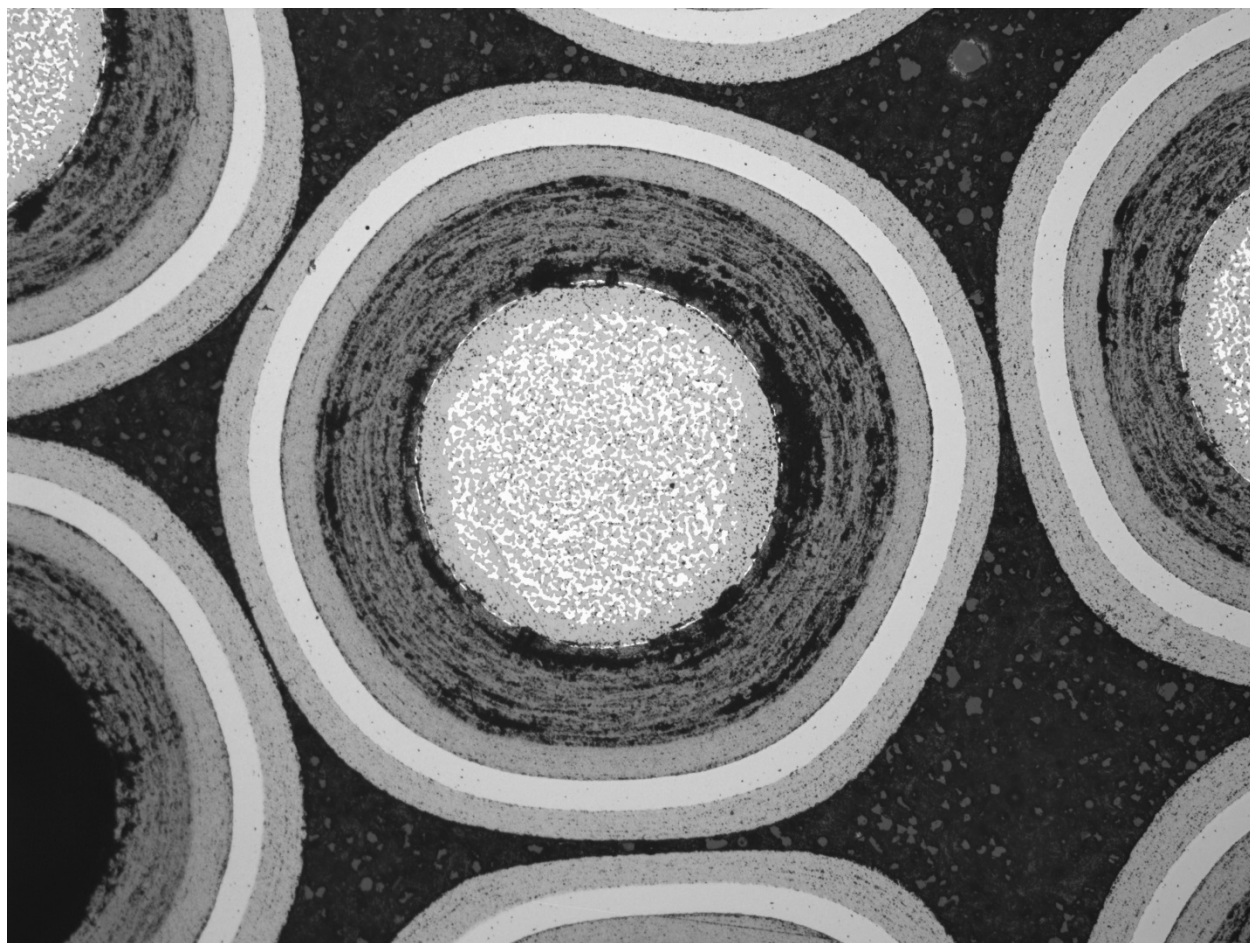


P16082301N306

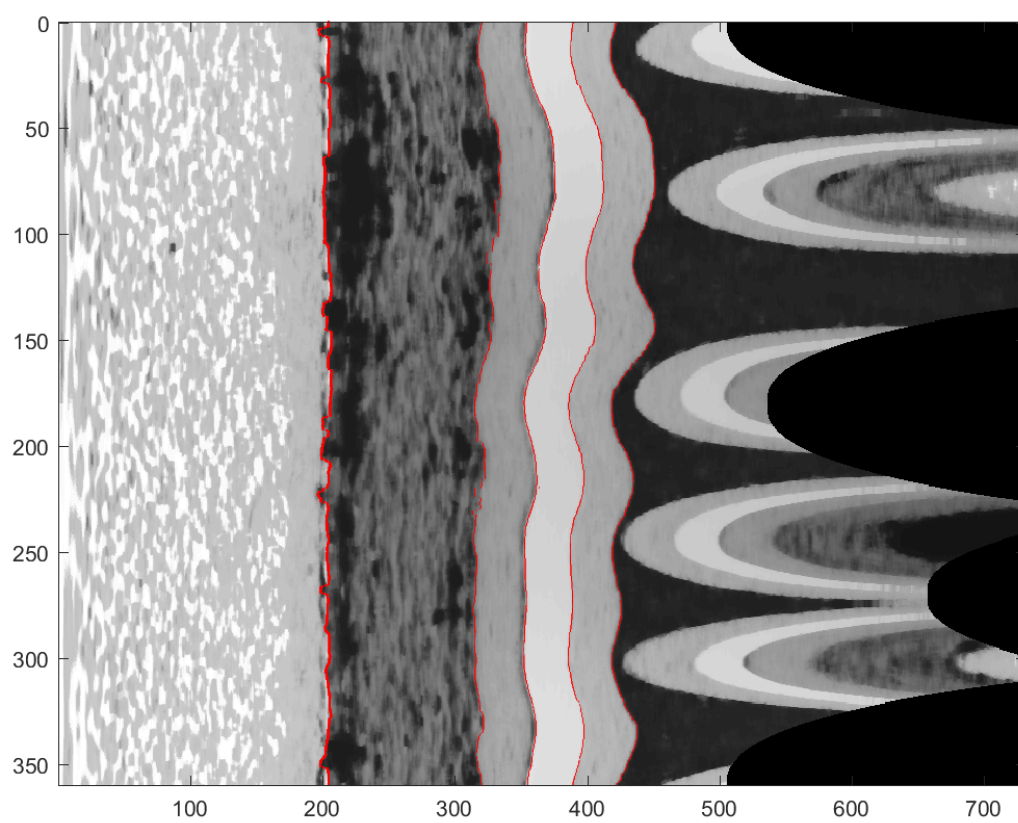


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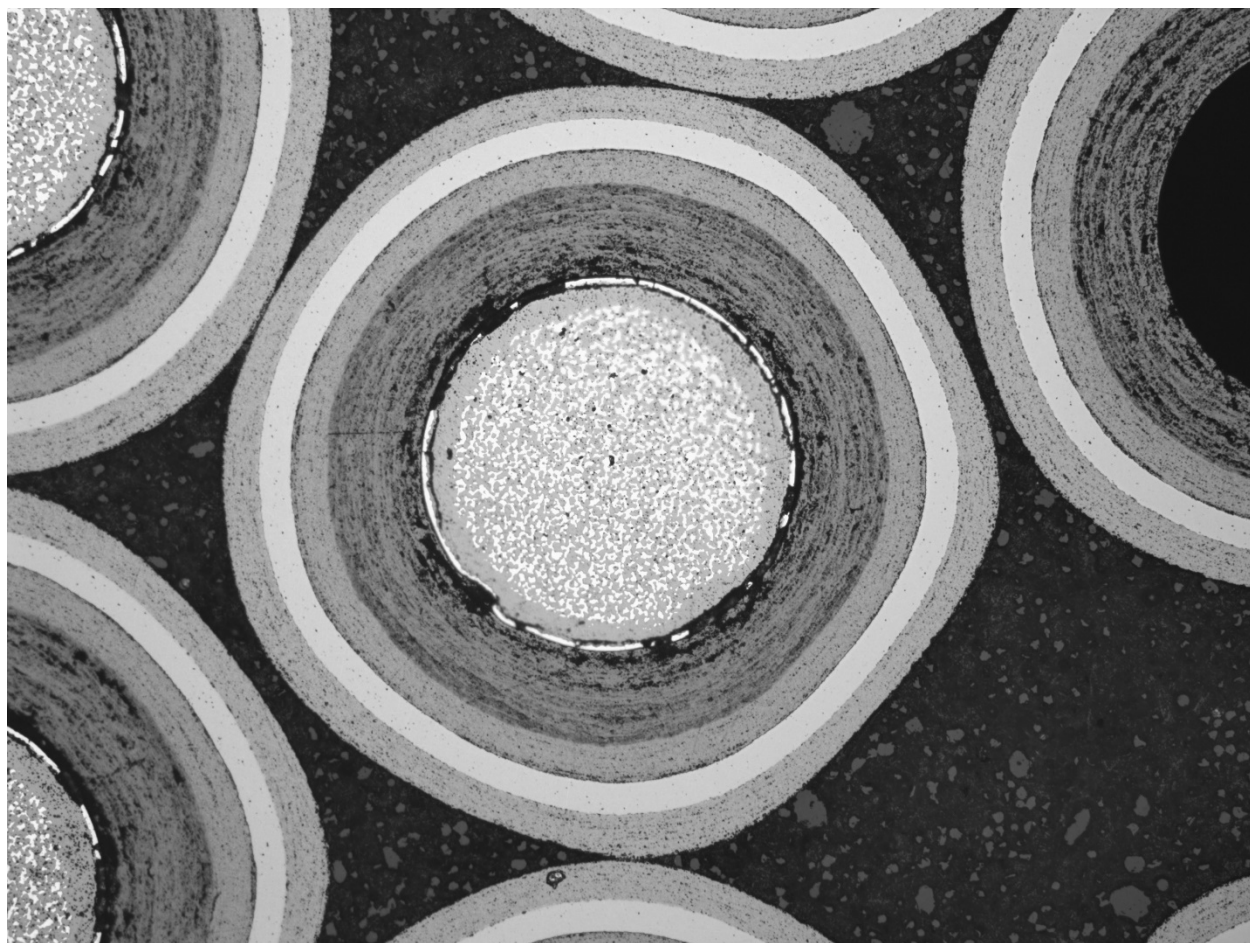




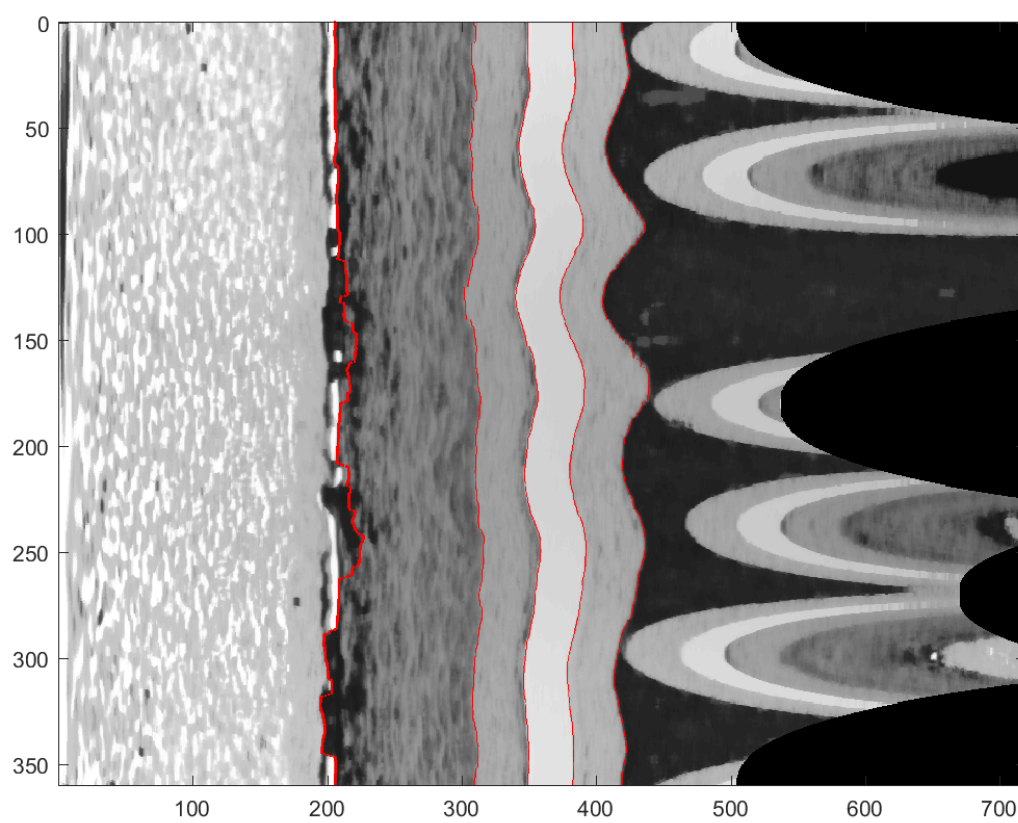
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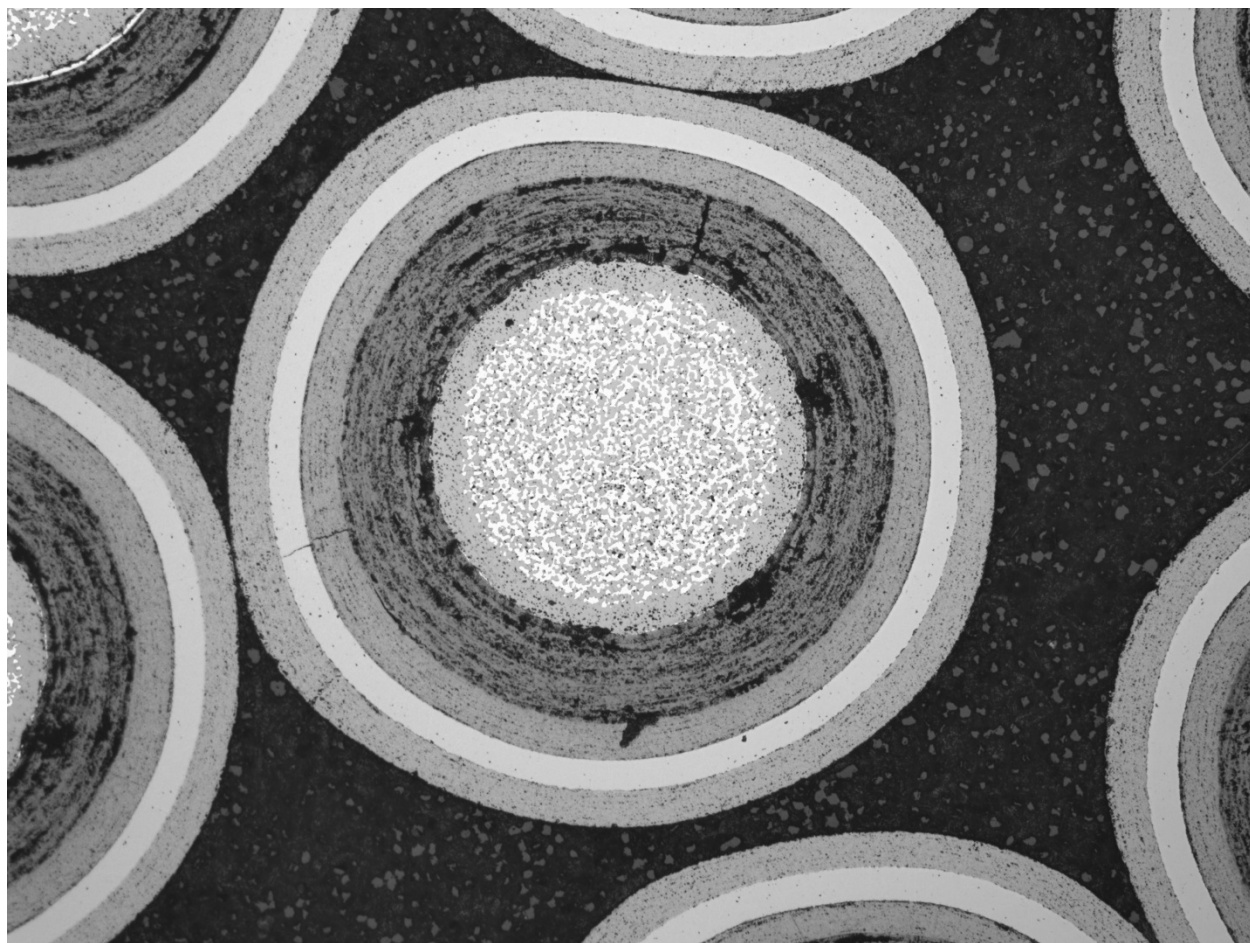
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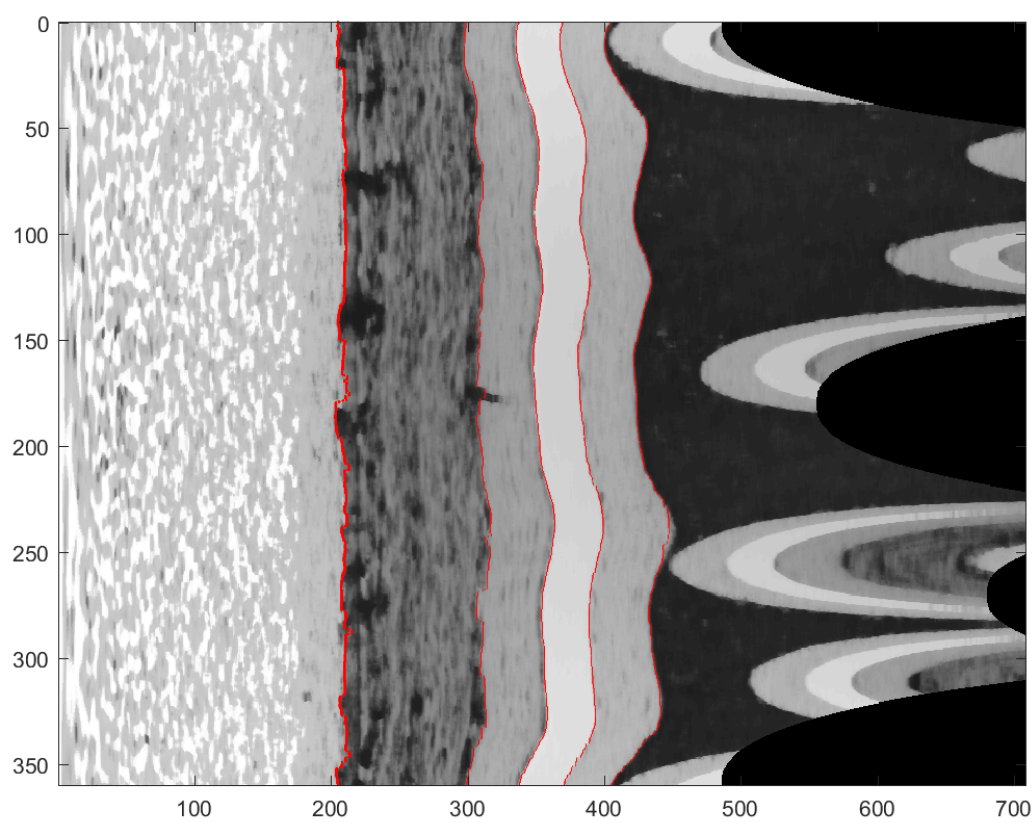
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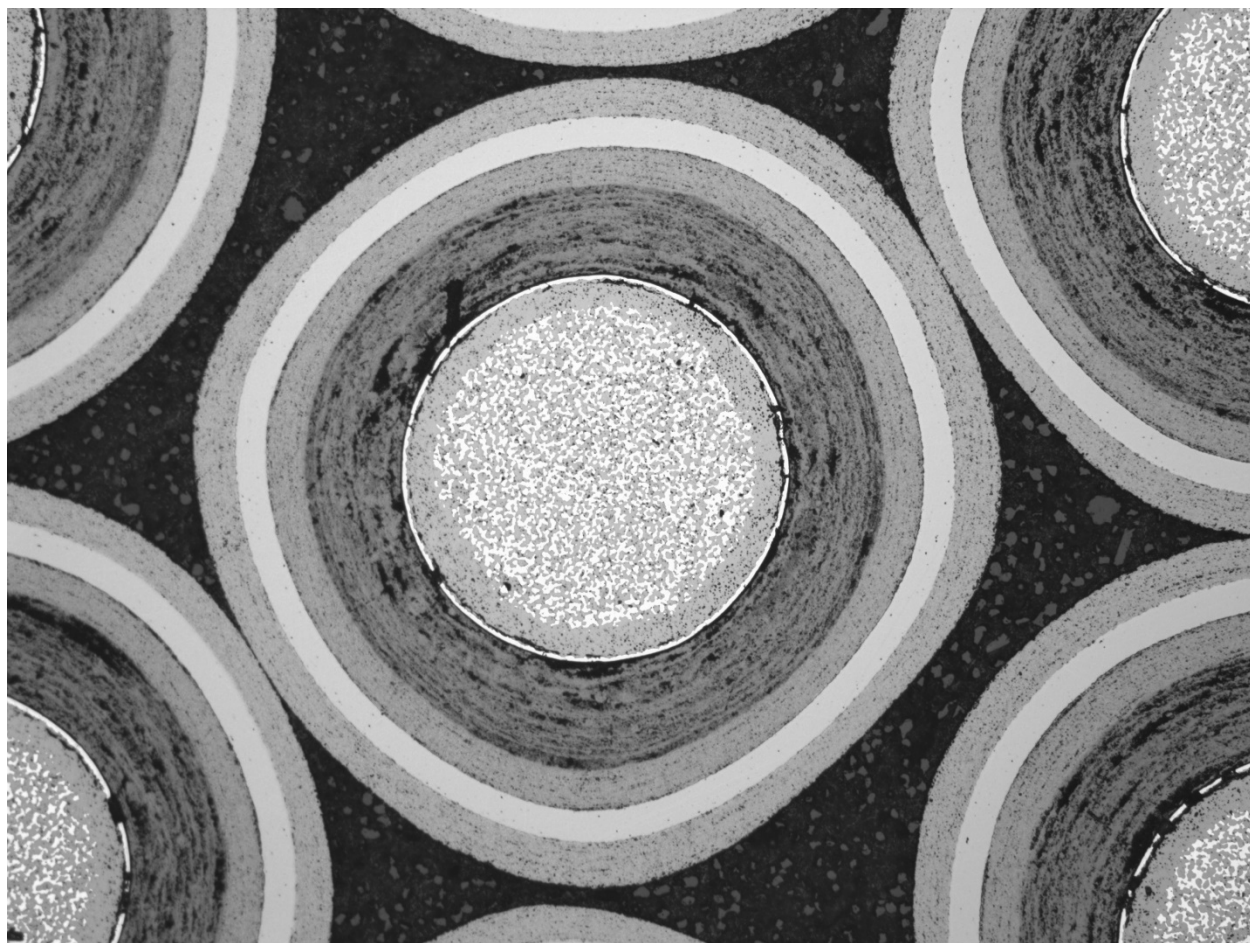


P16082301N309

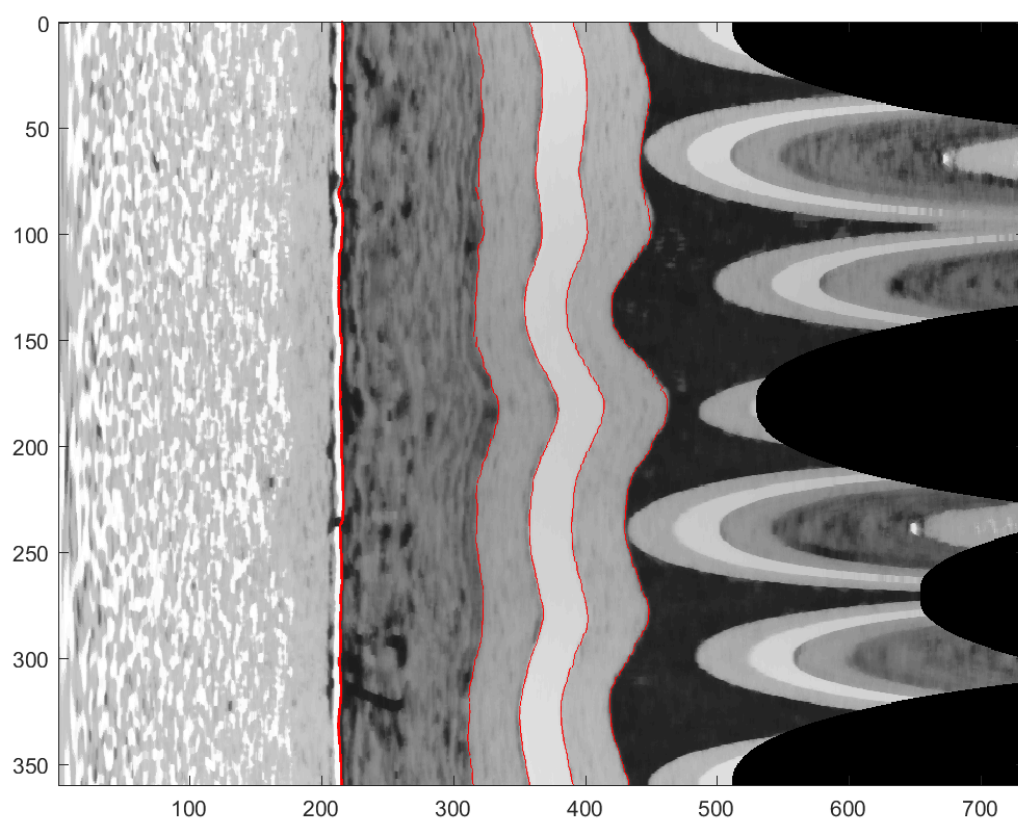


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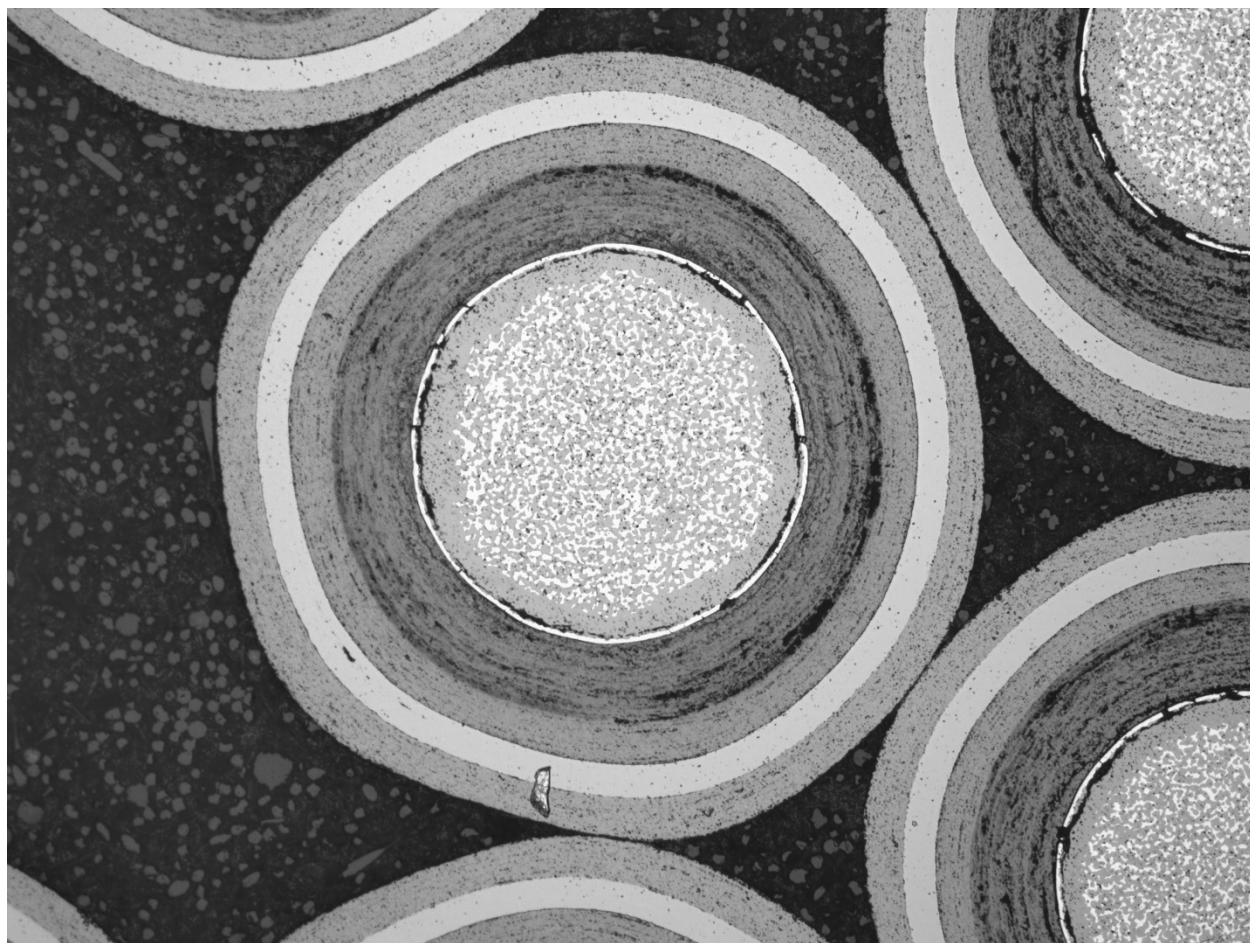




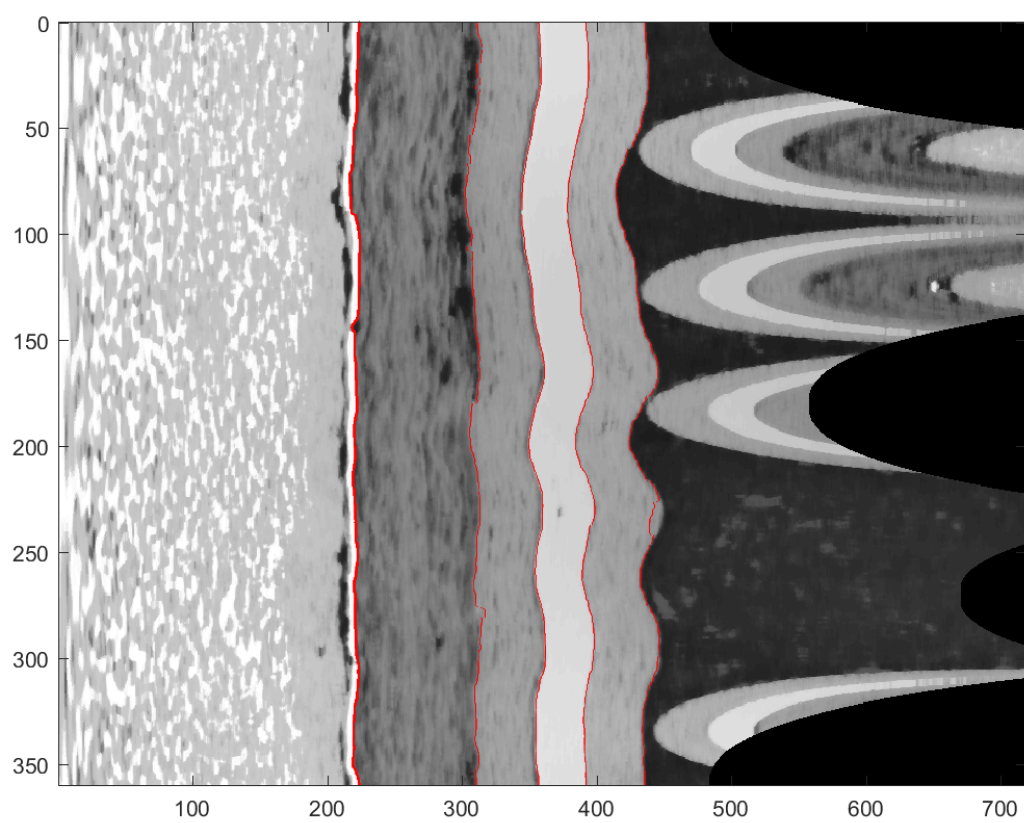
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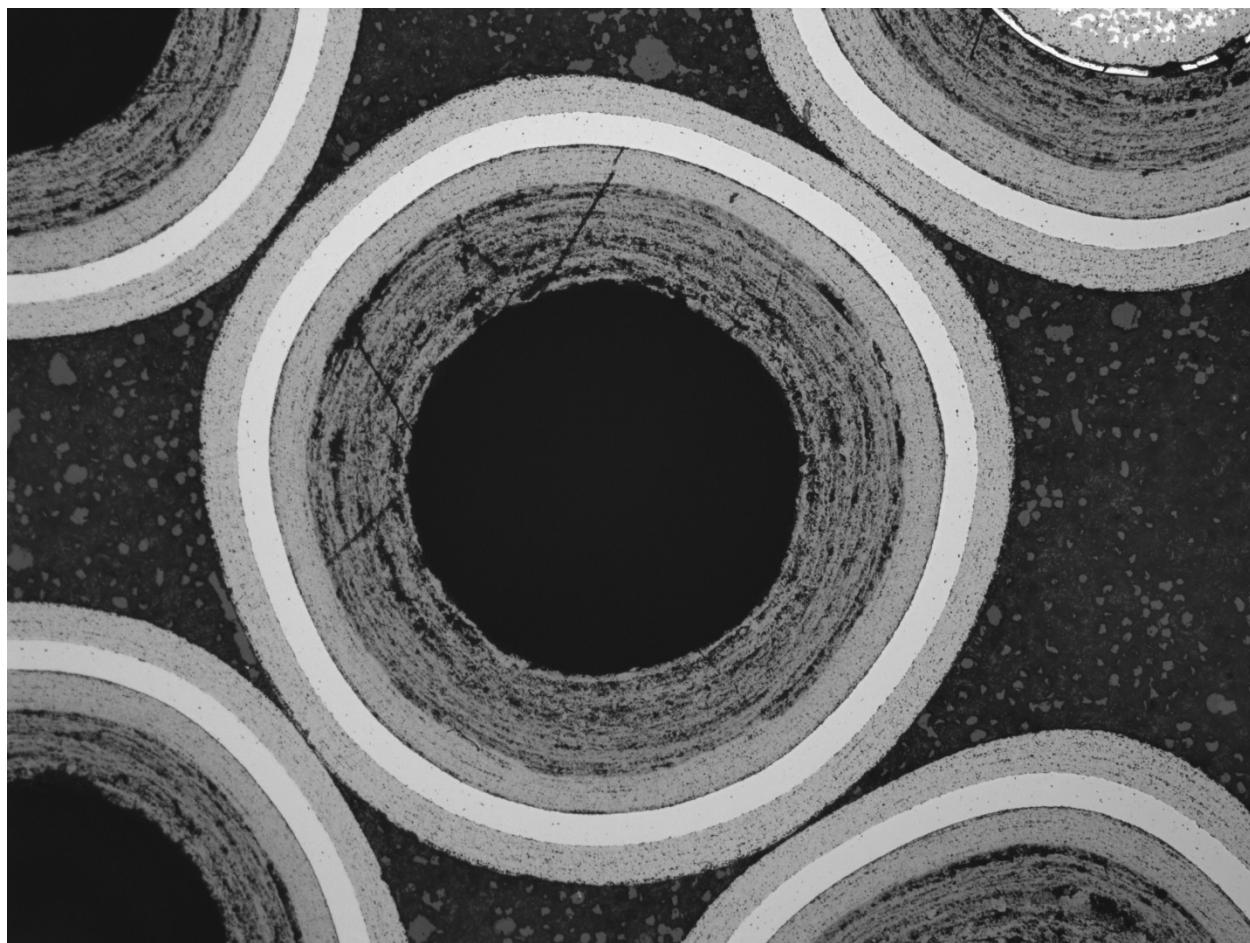
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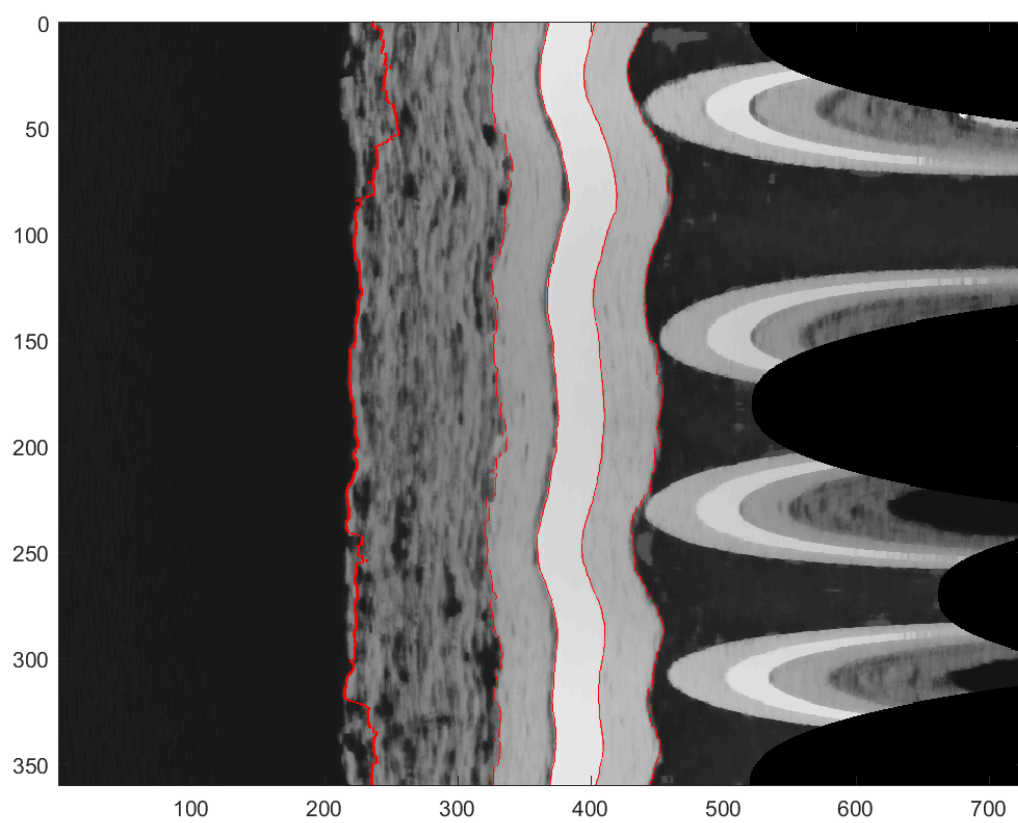
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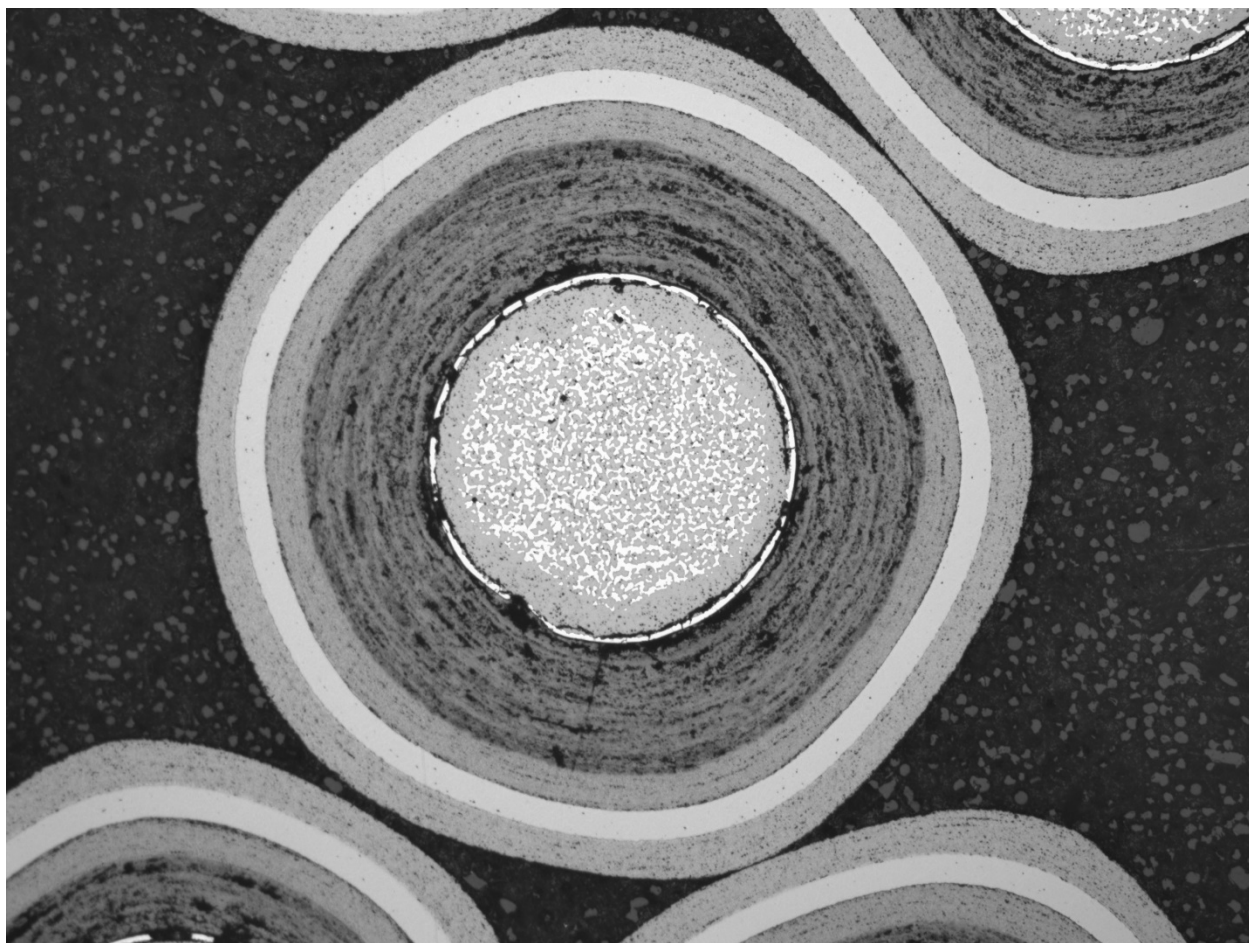


P16082301N312

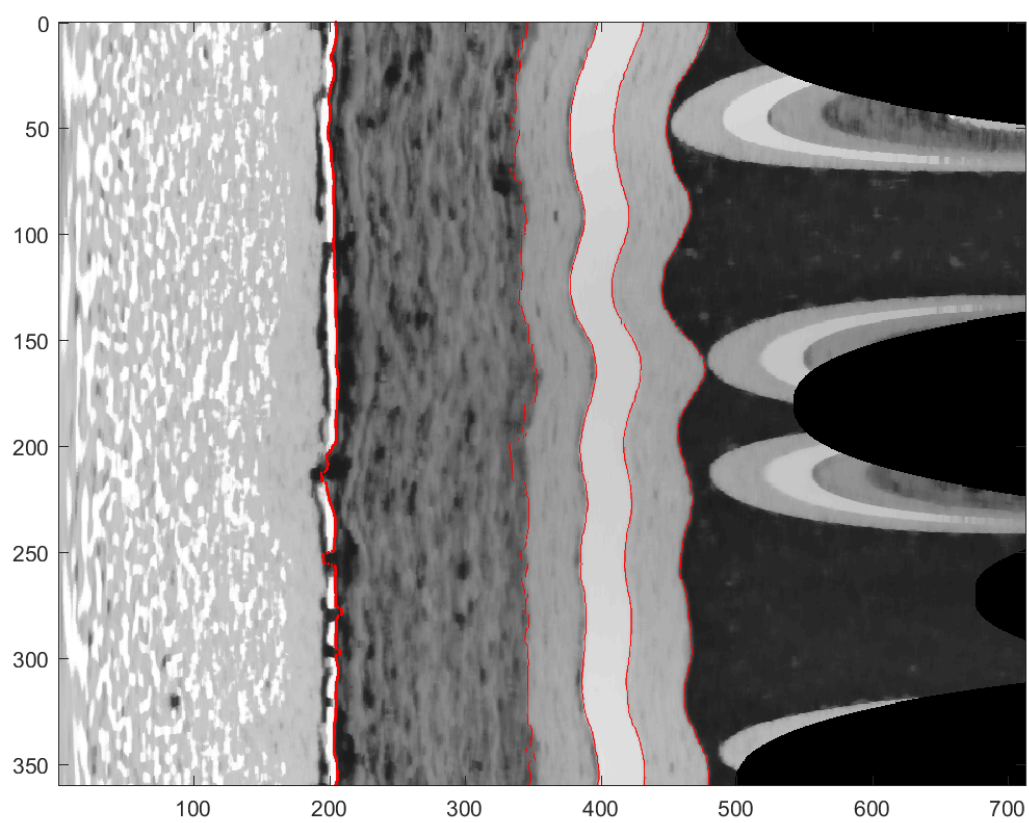


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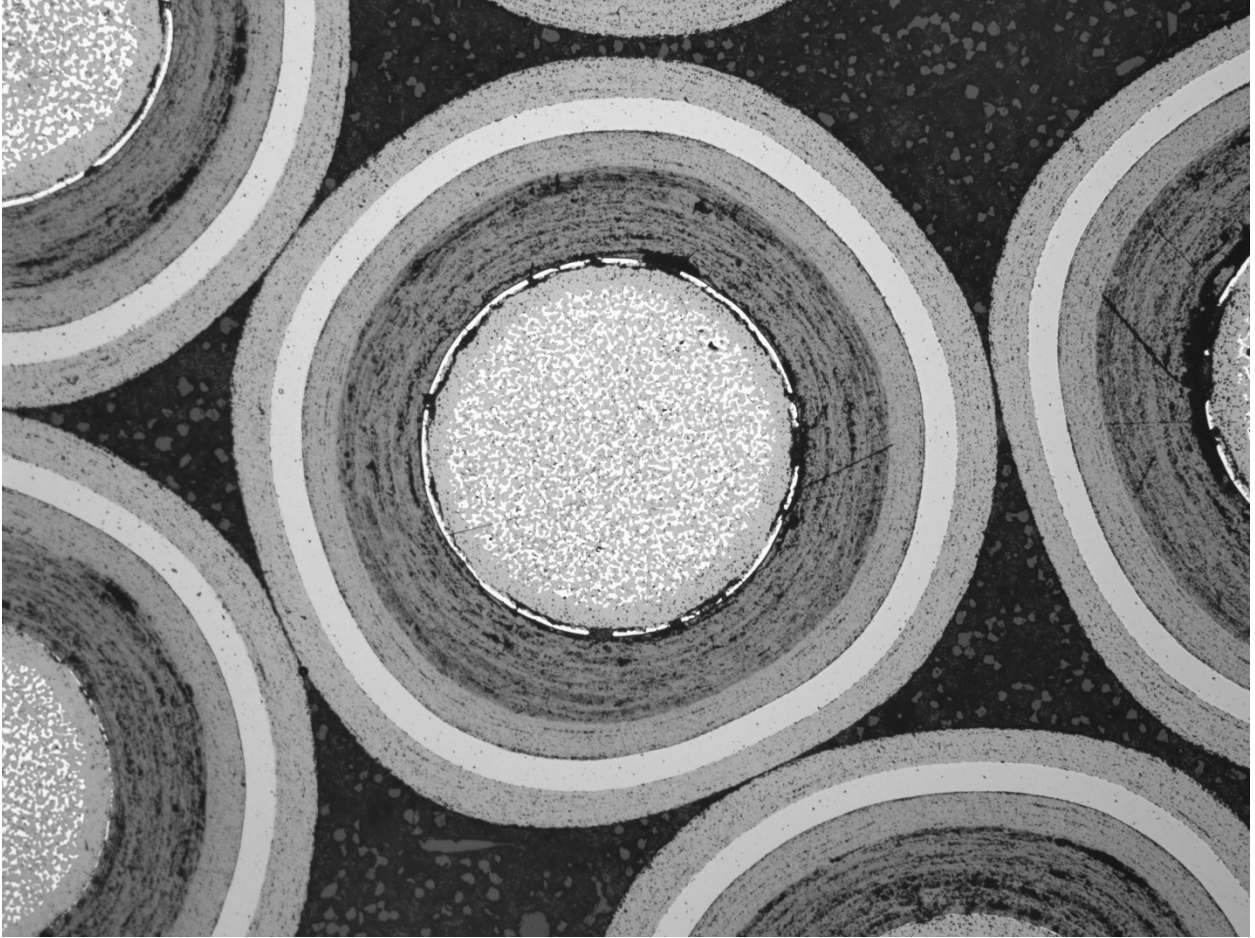




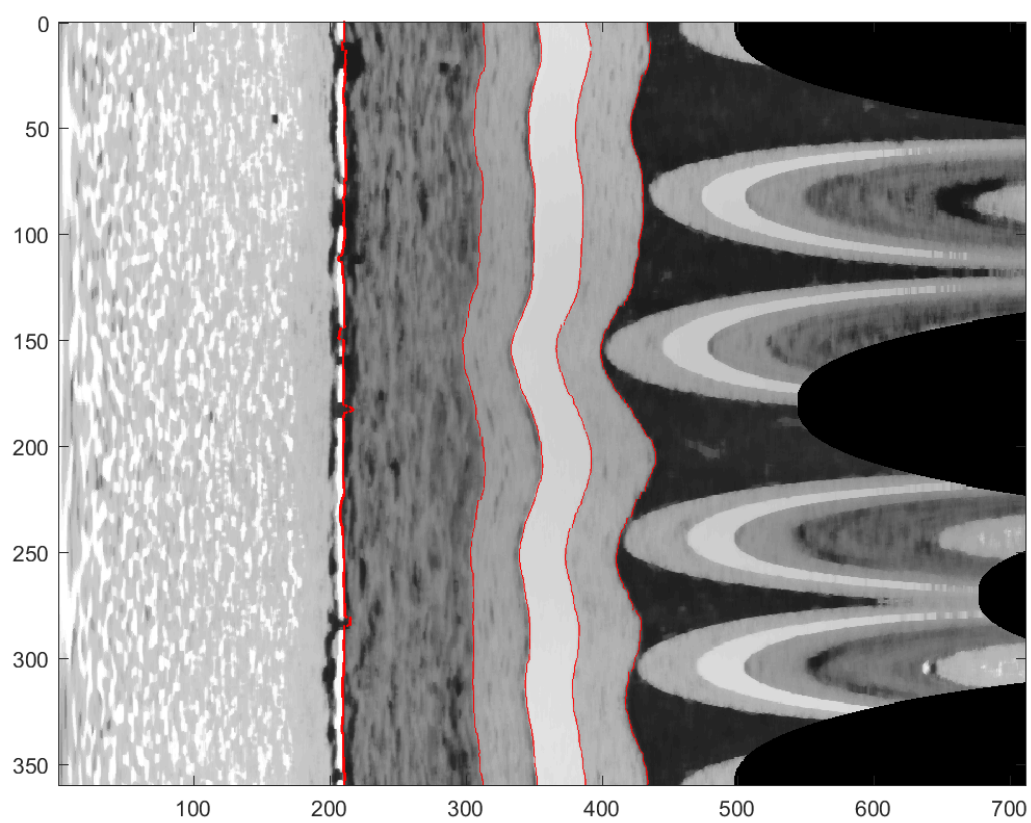
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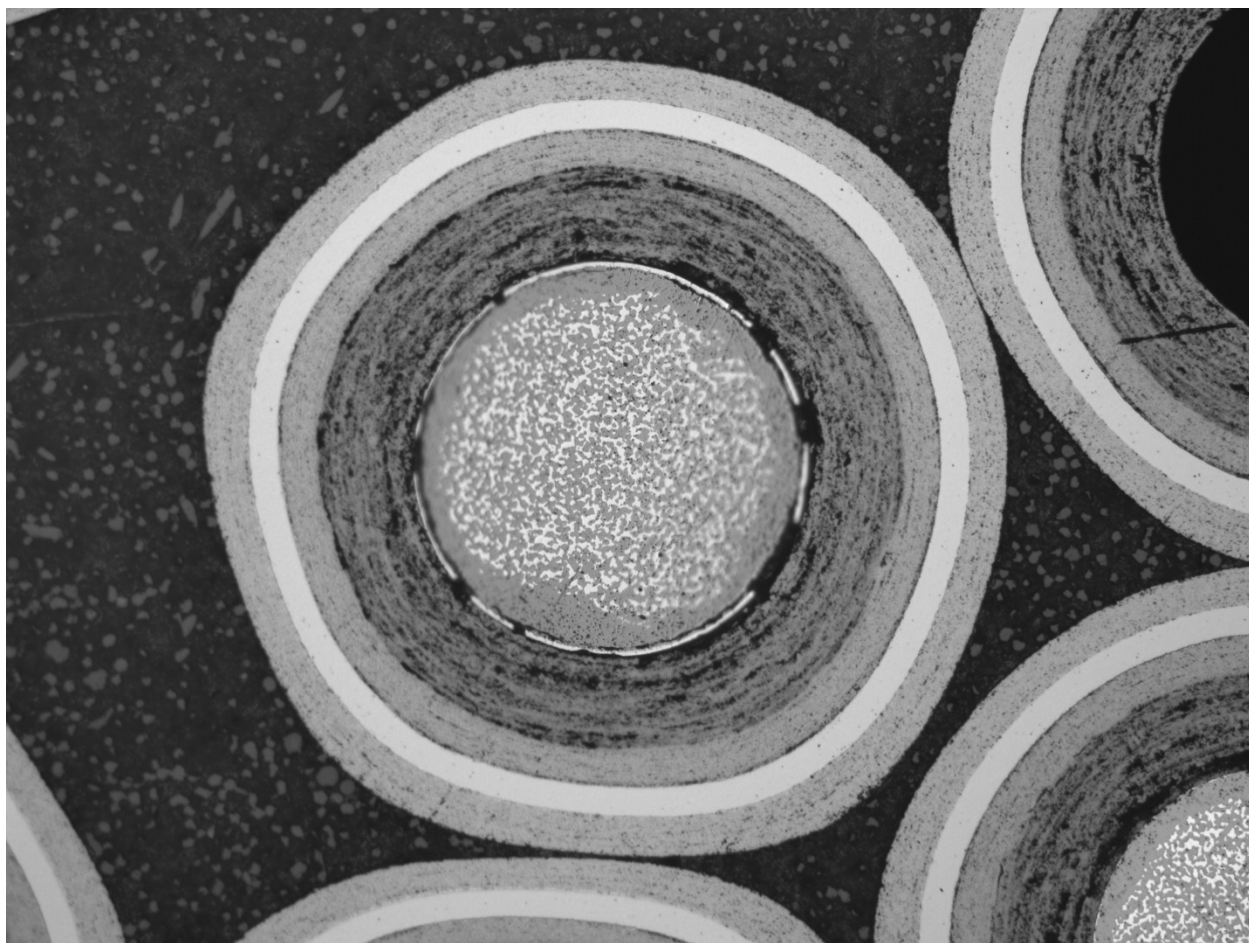
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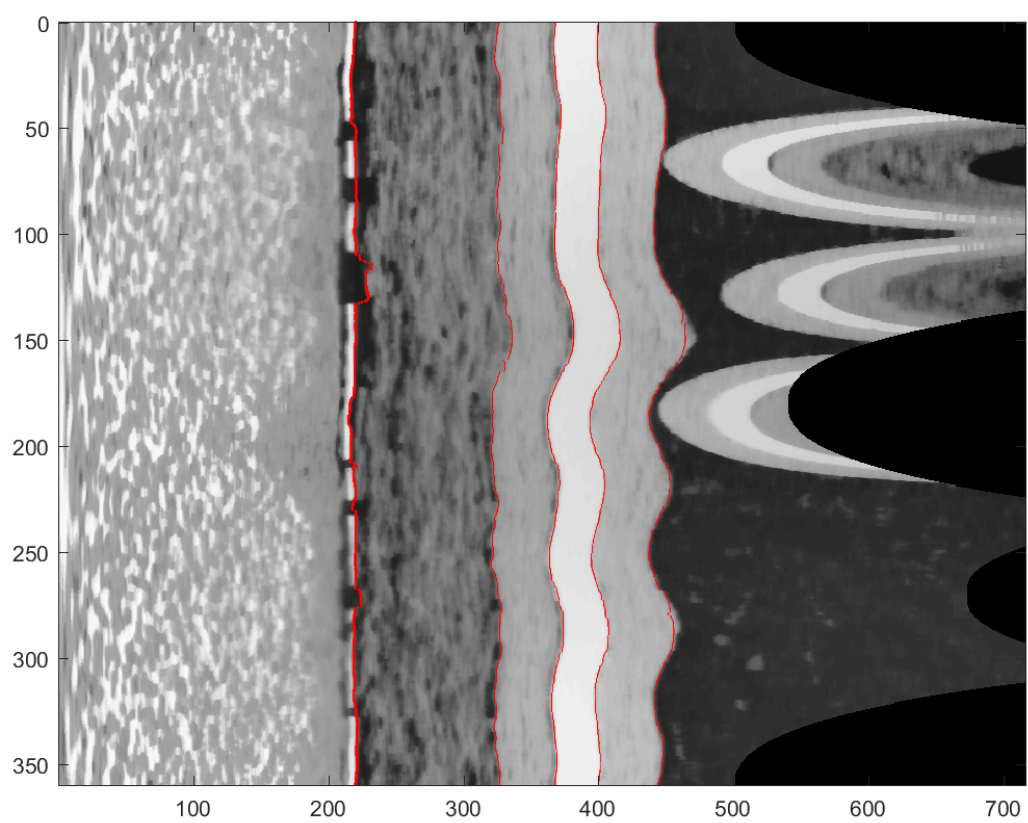
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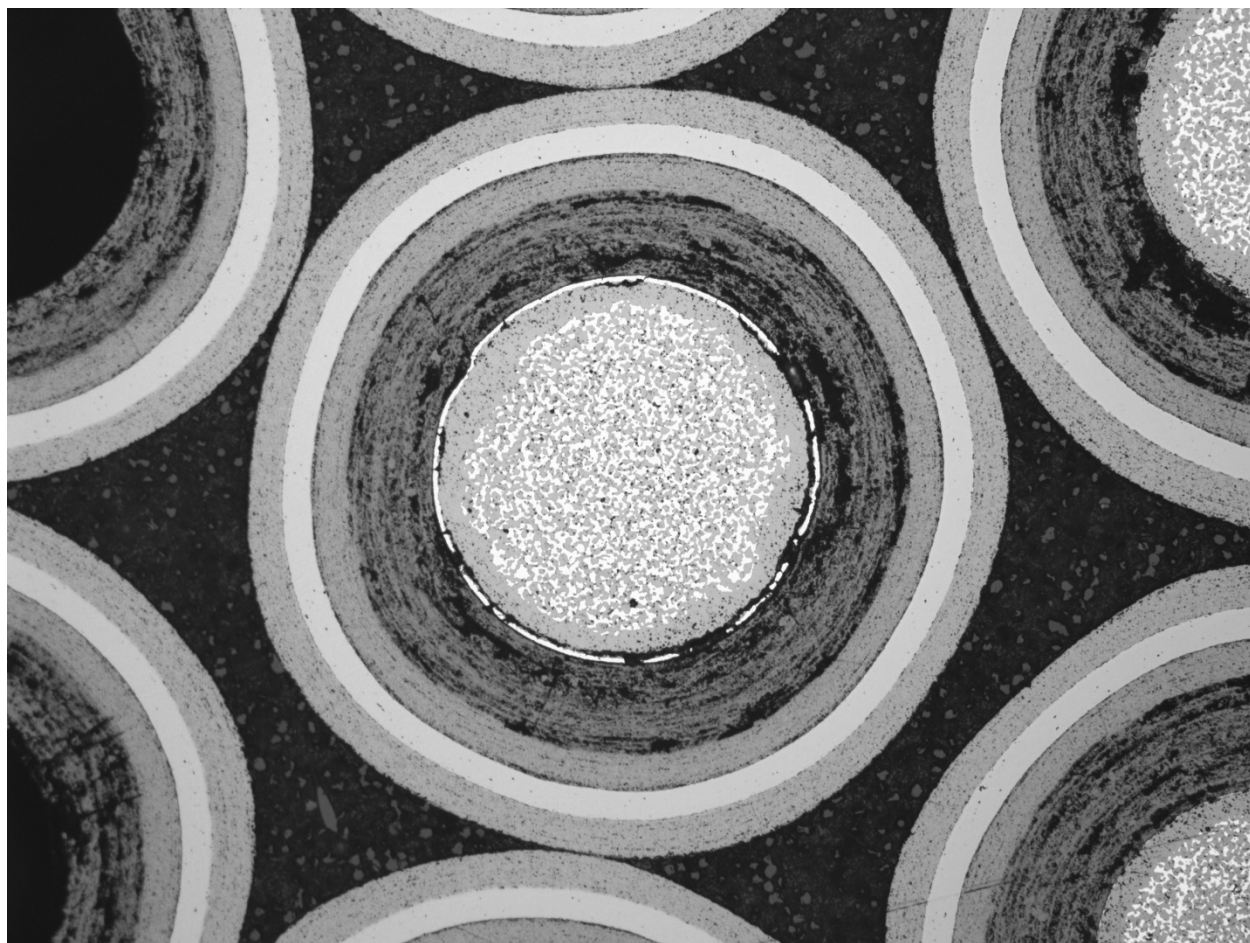


P16082301N319

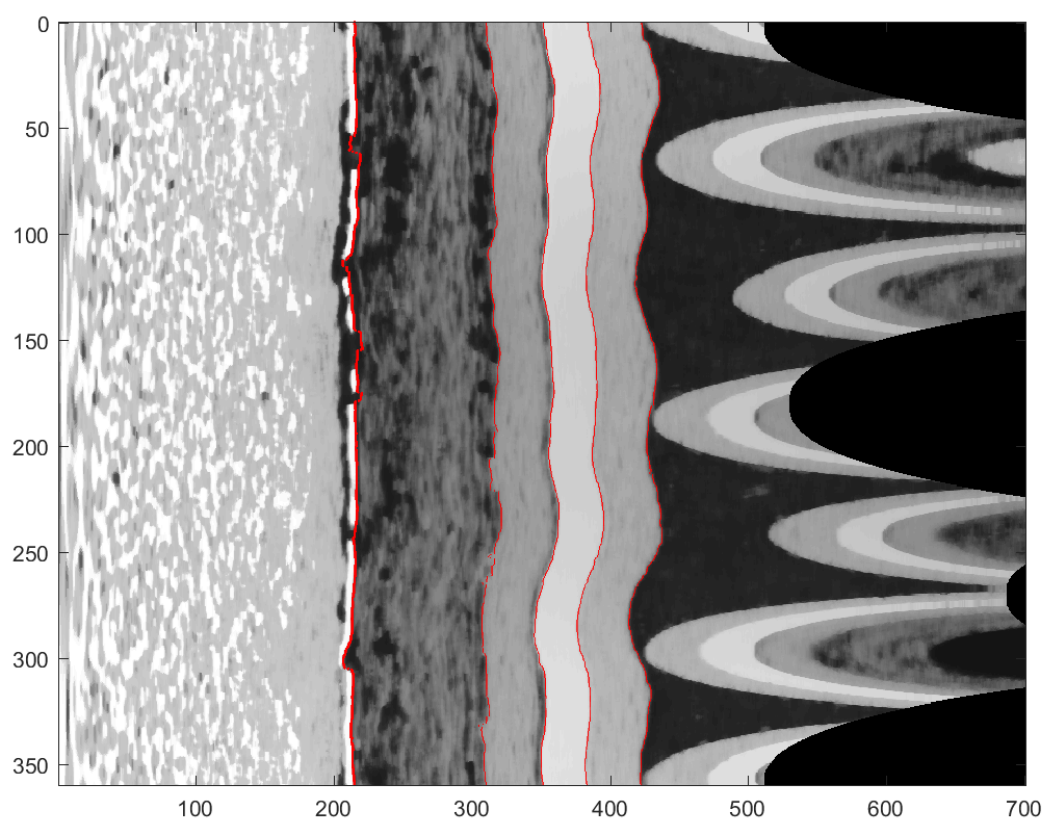


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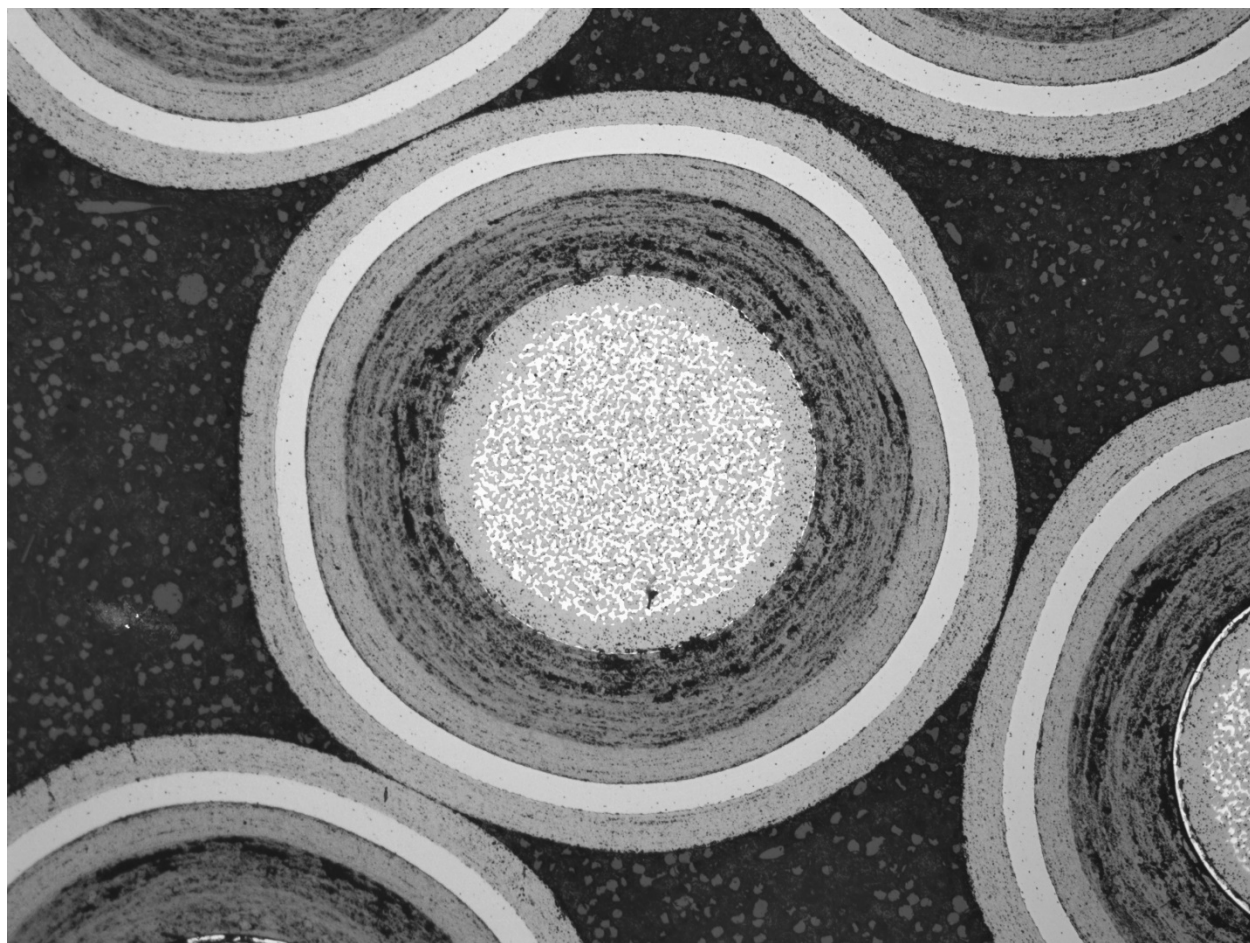




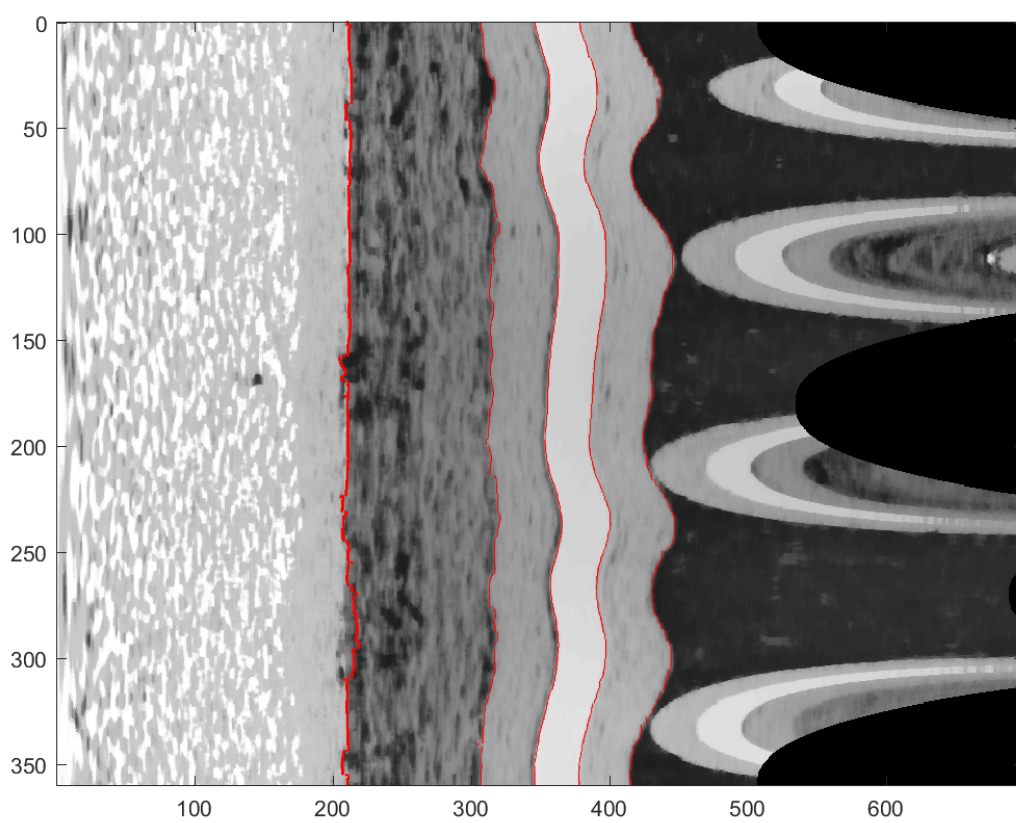
P16082301N328



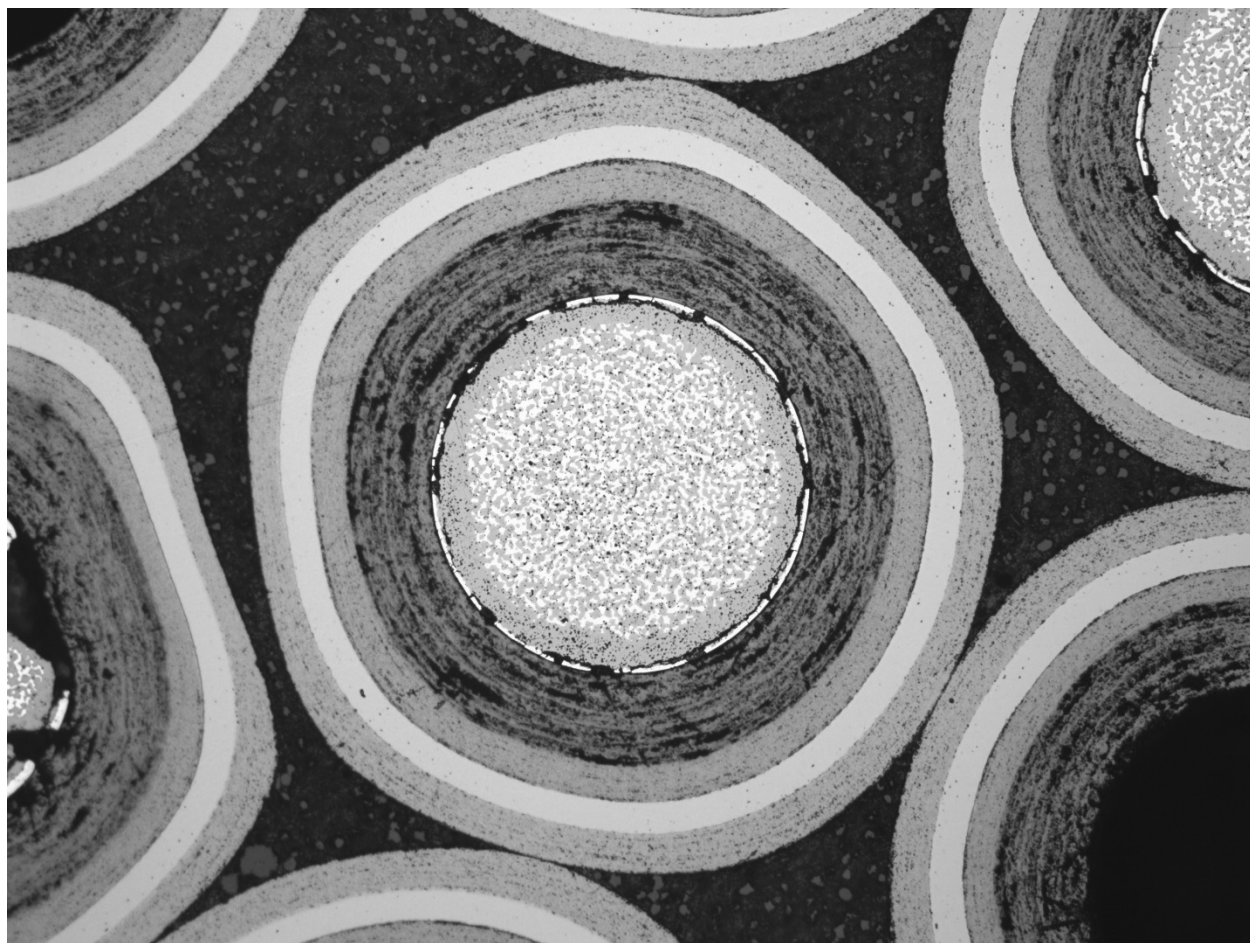
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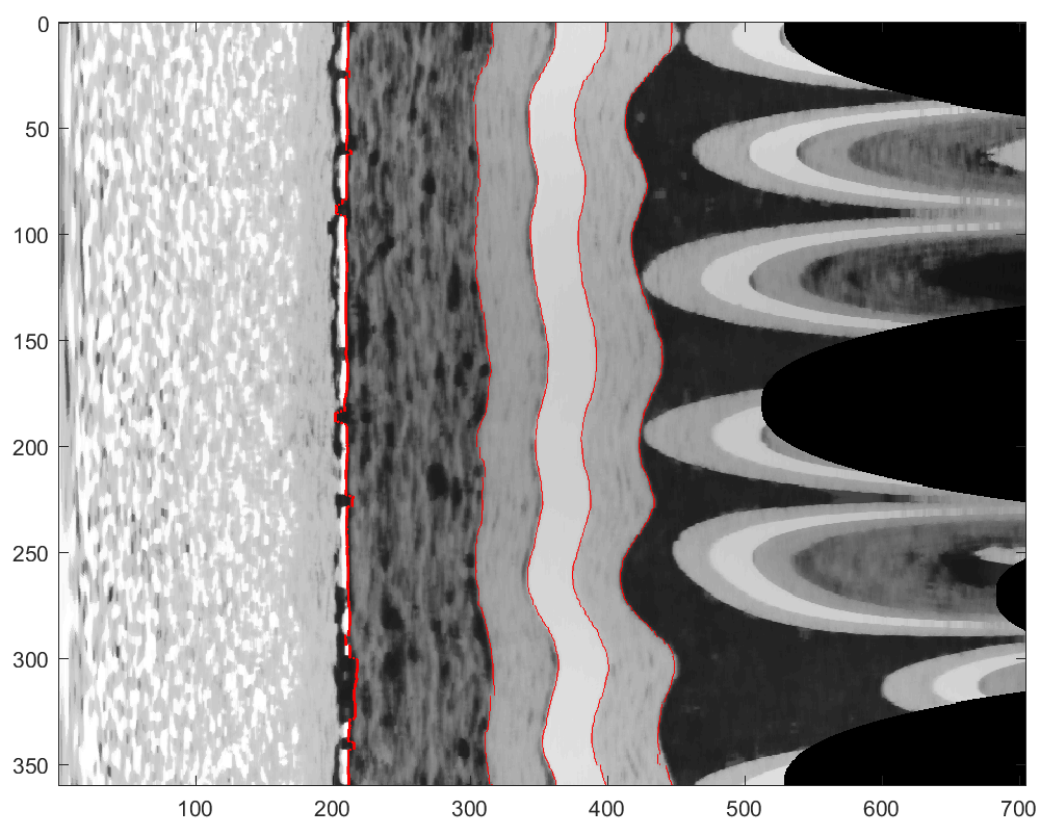
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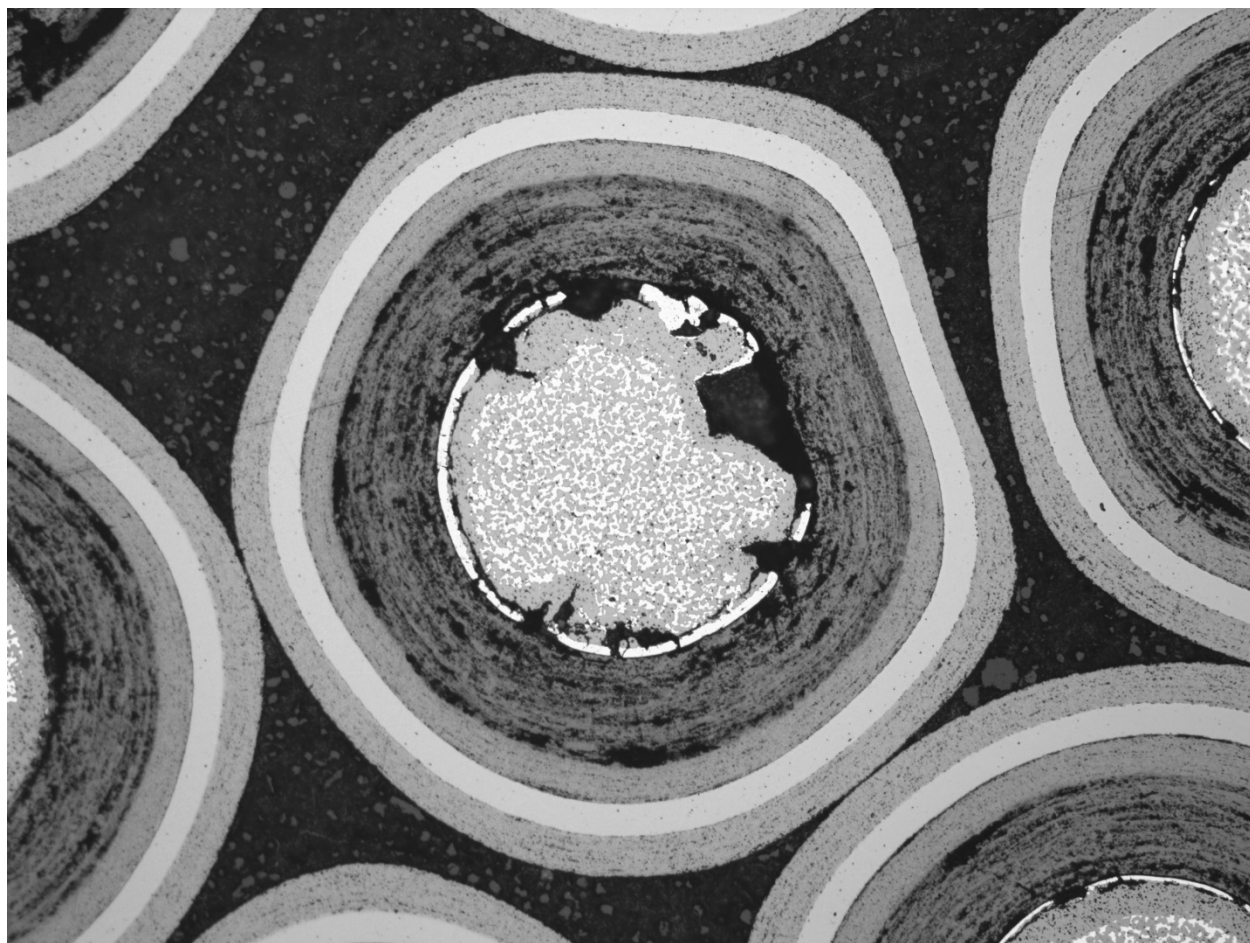


P16082301N330

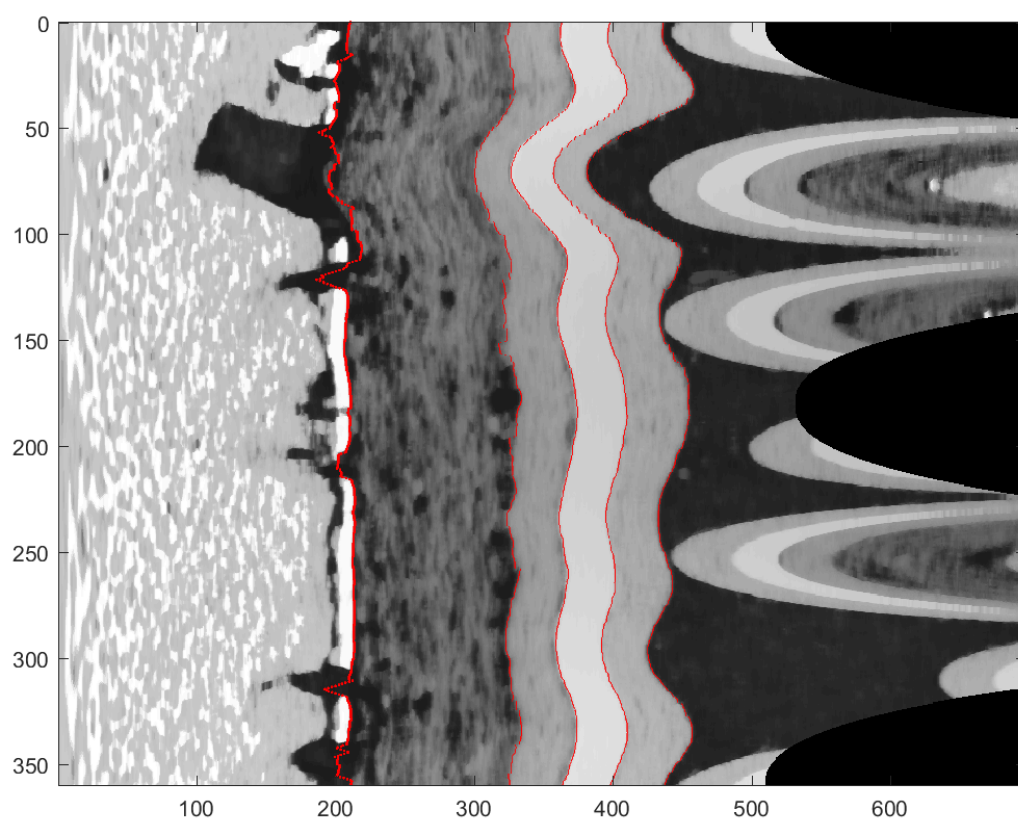


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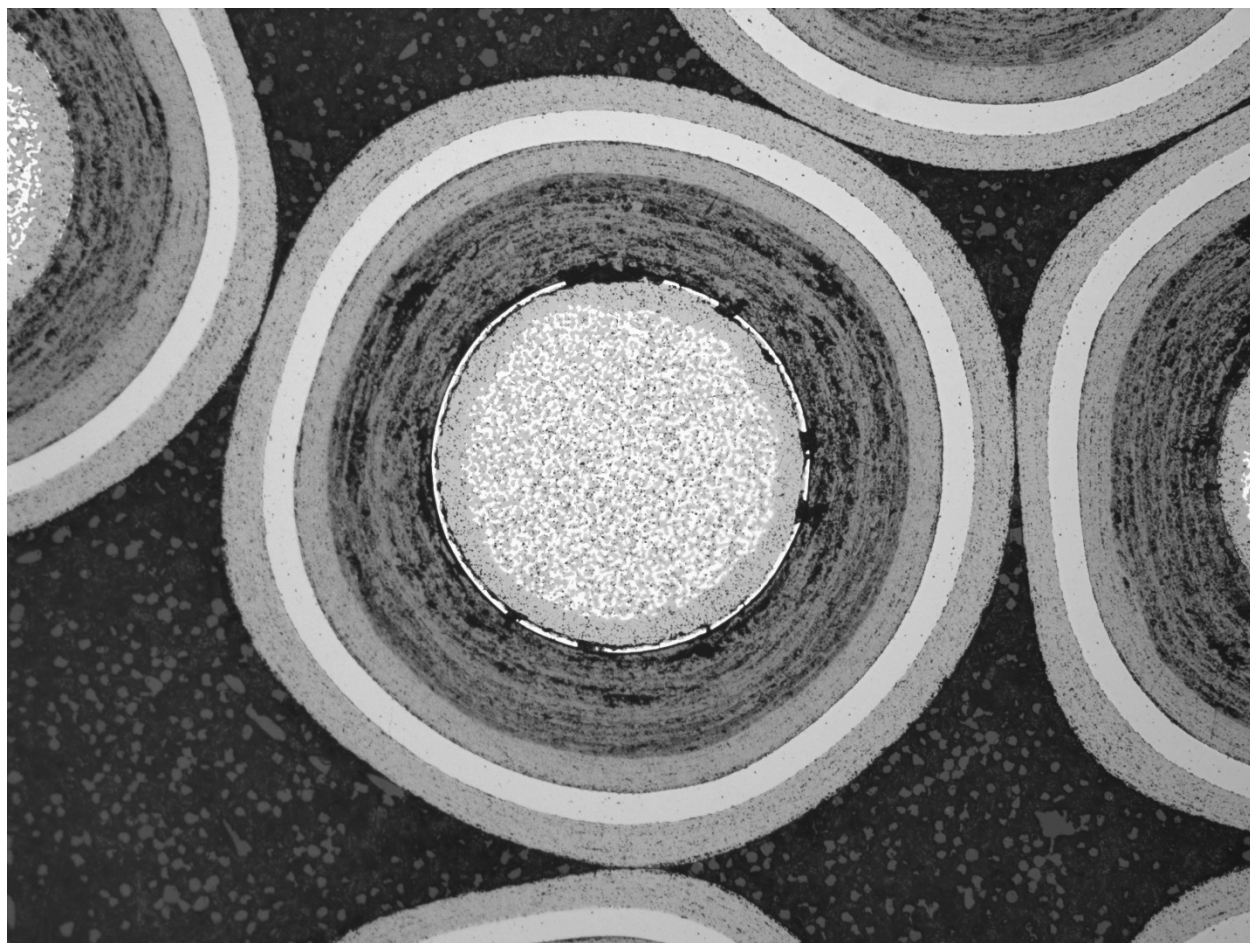




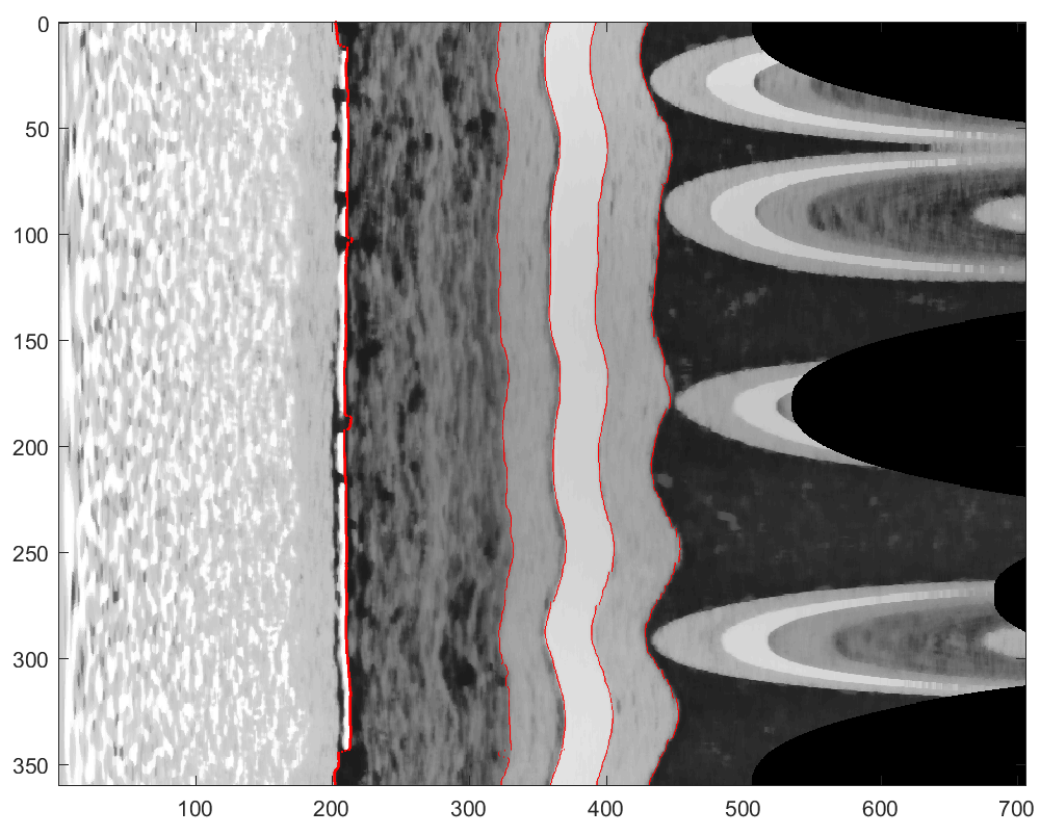
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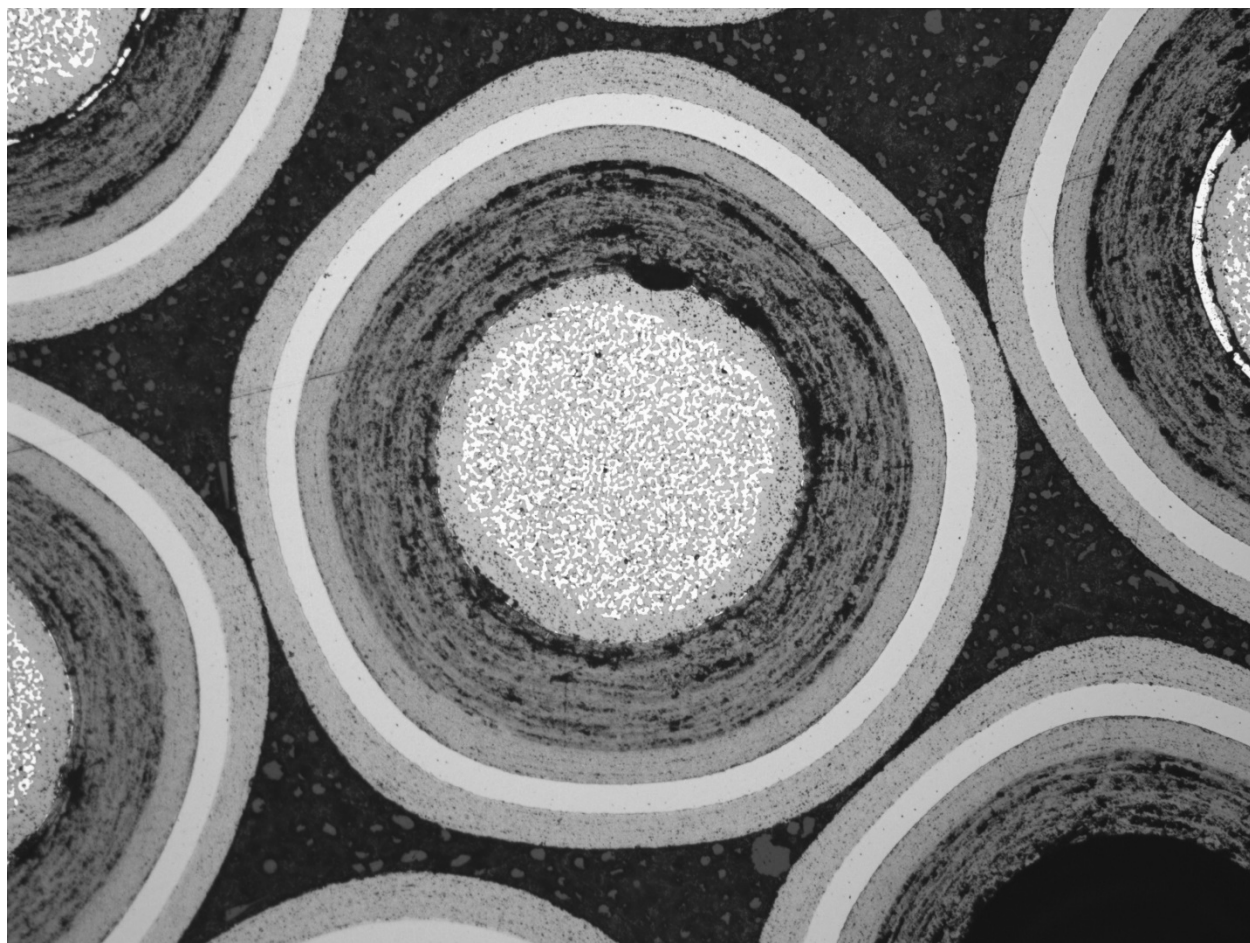
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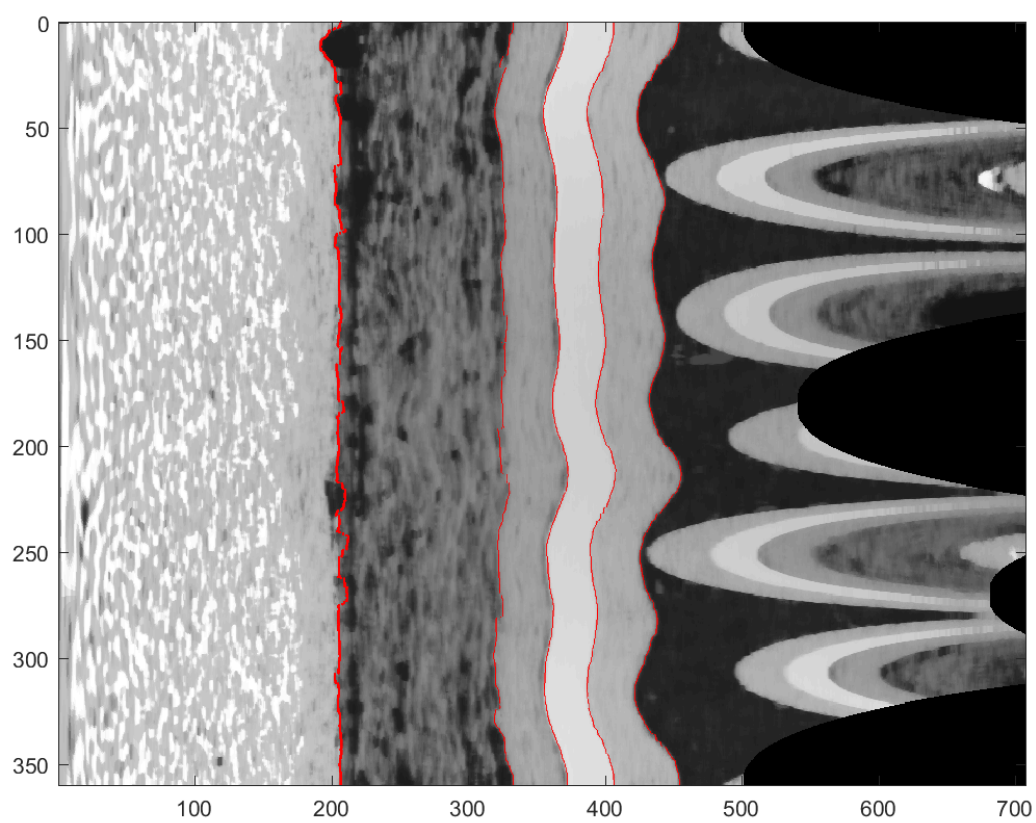
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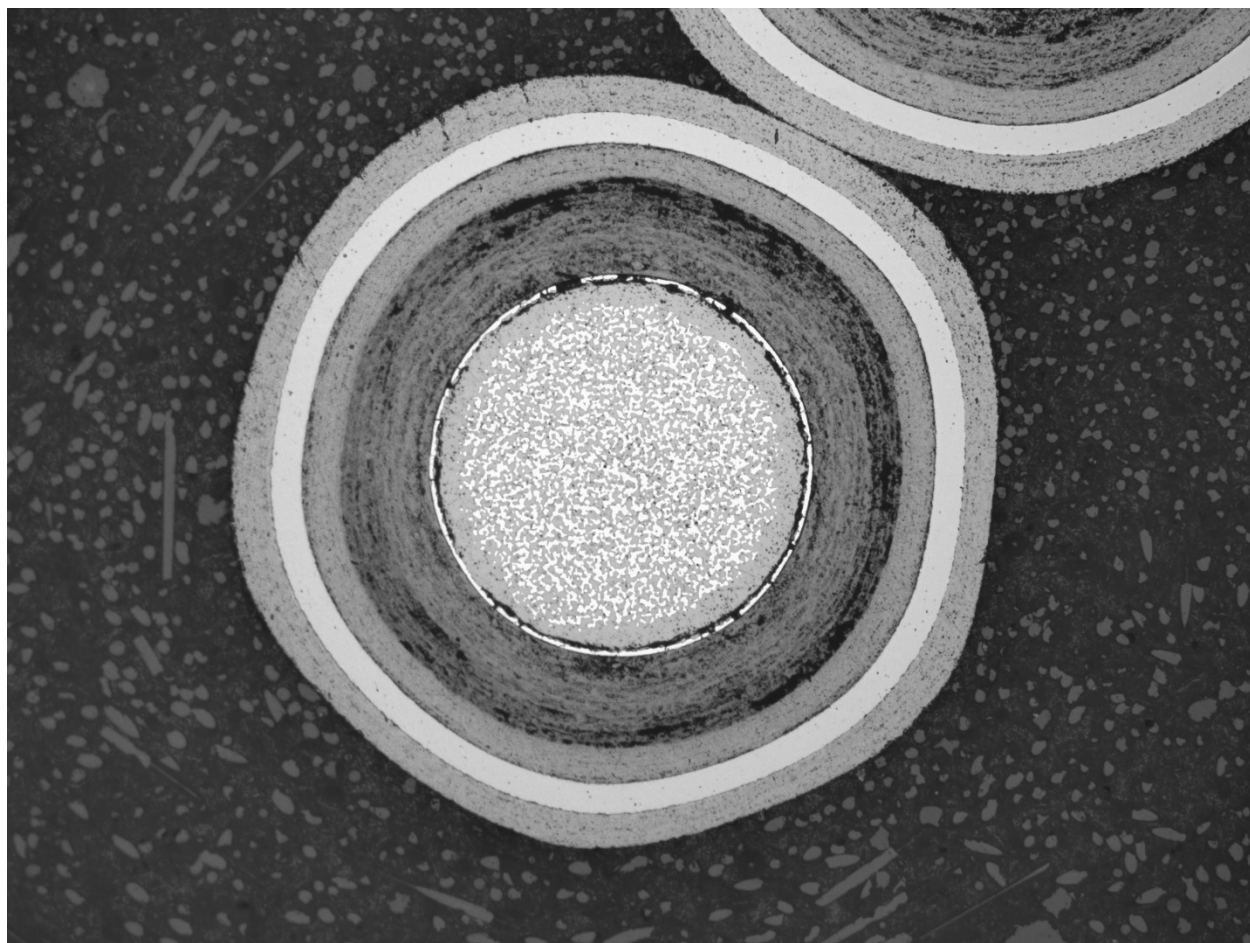


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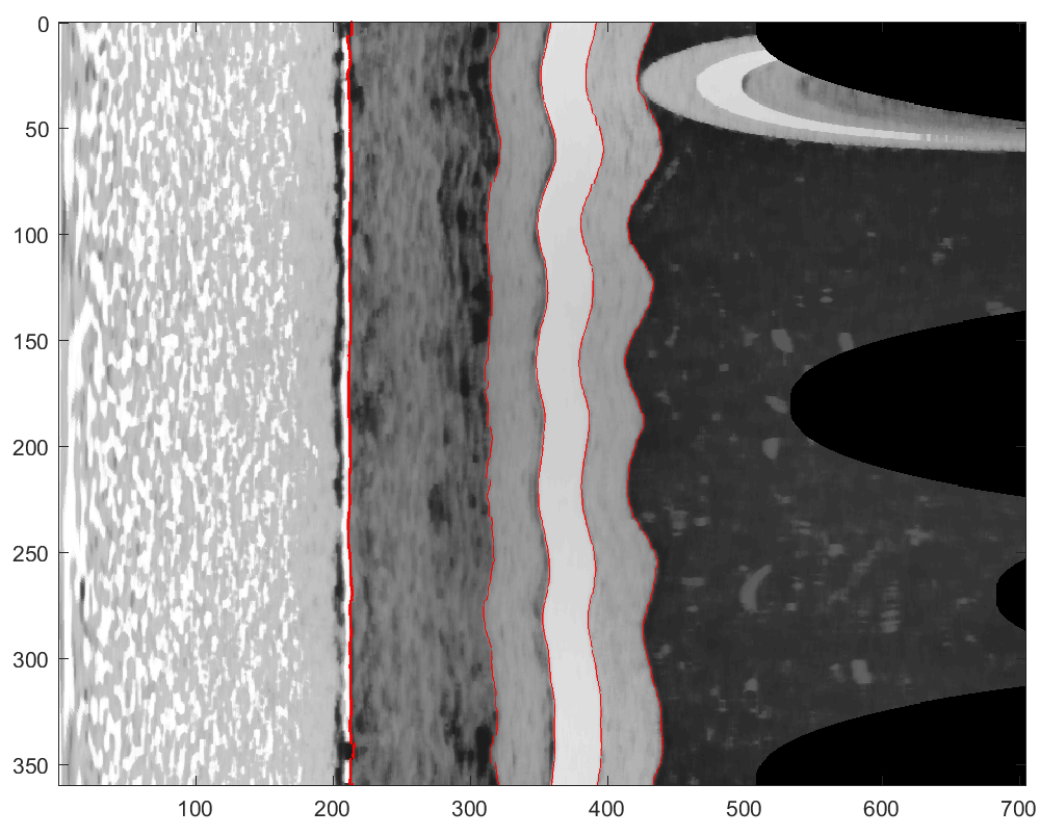


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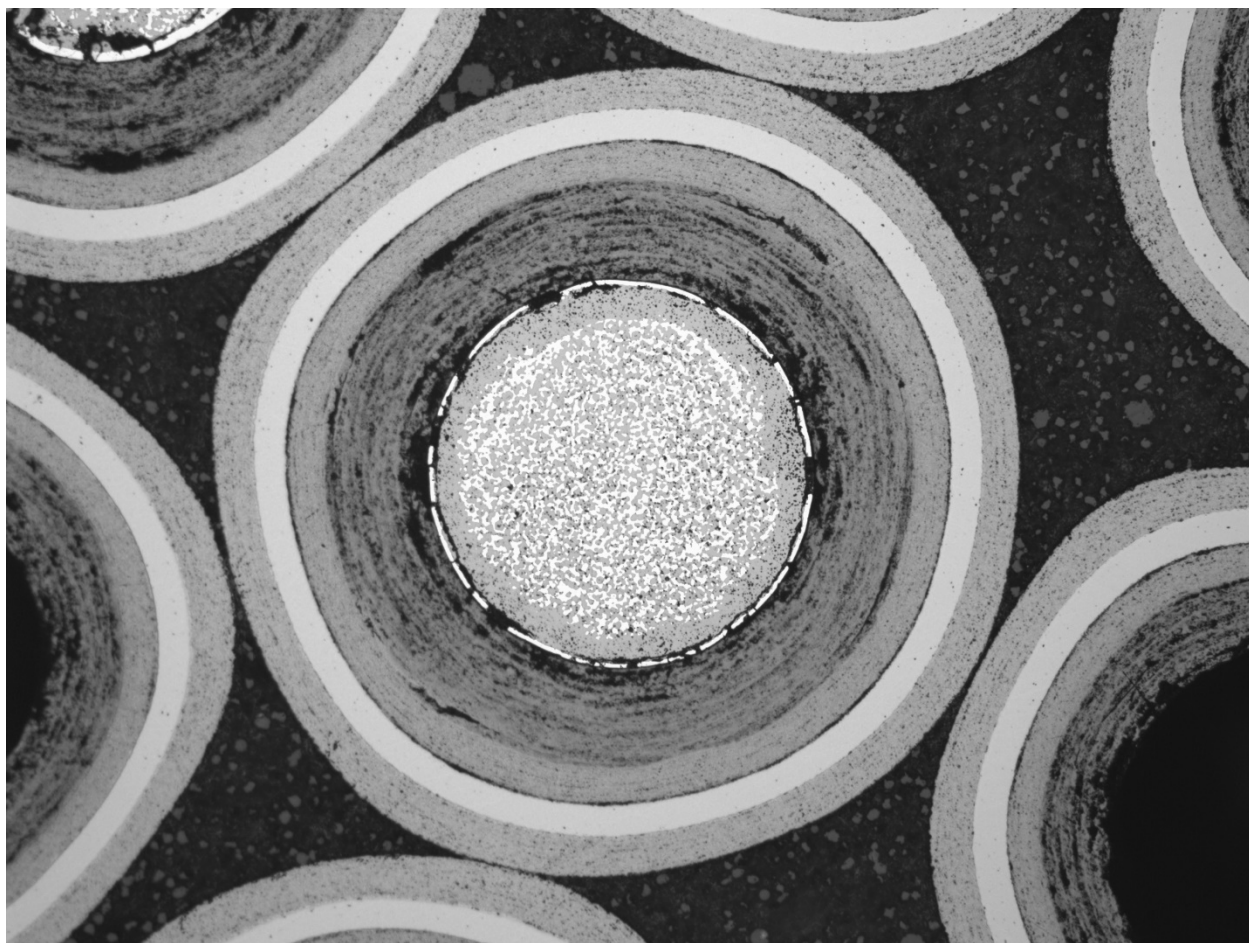




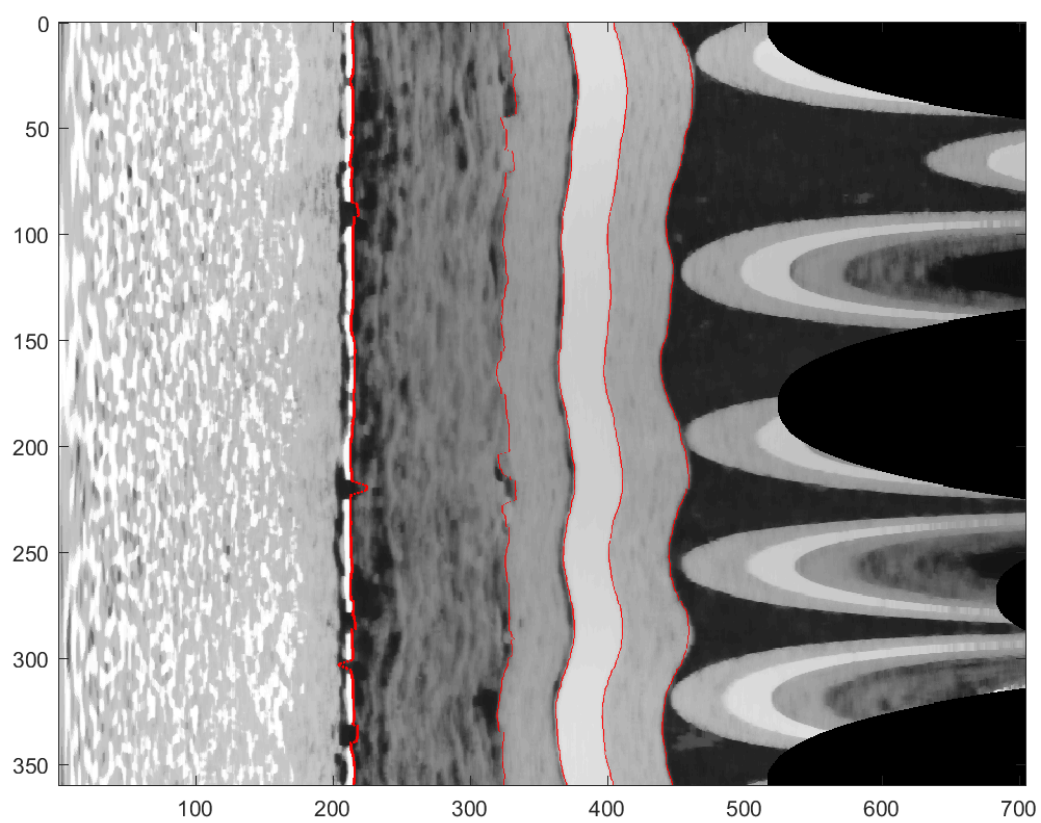
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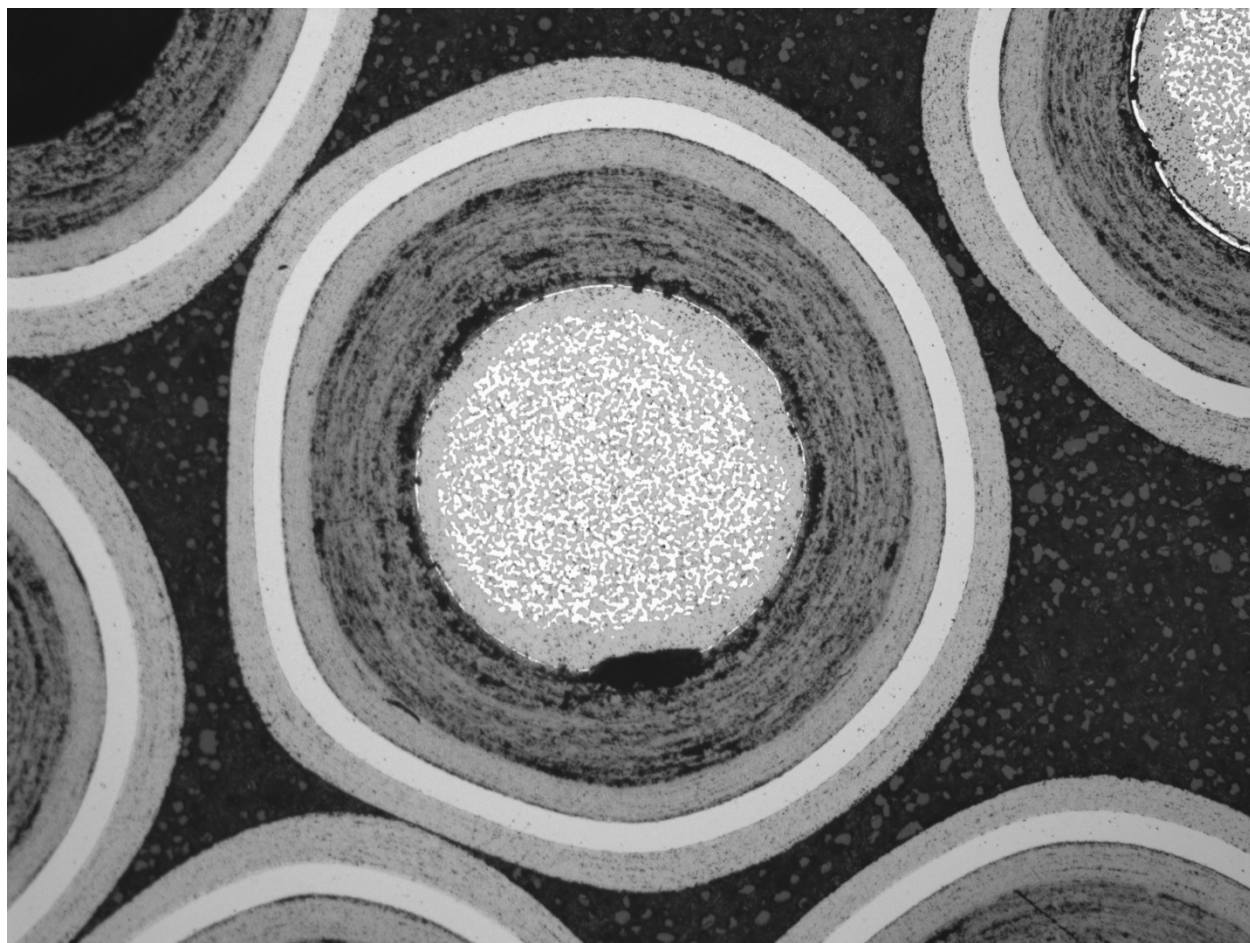
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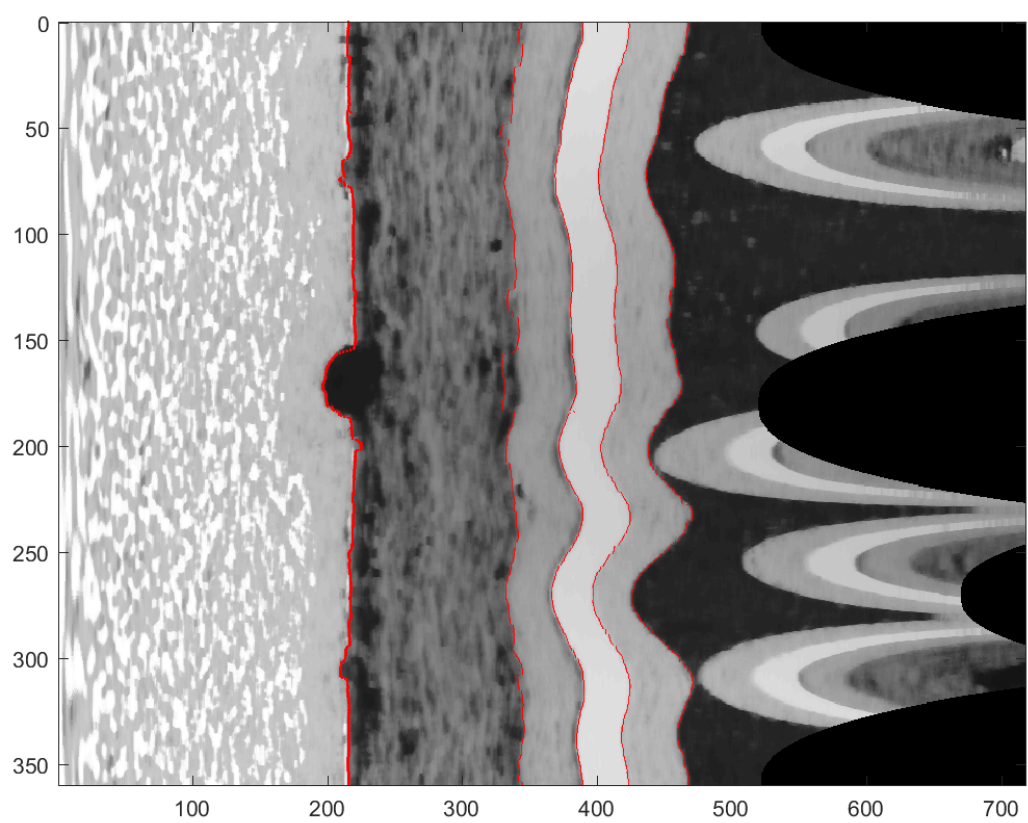
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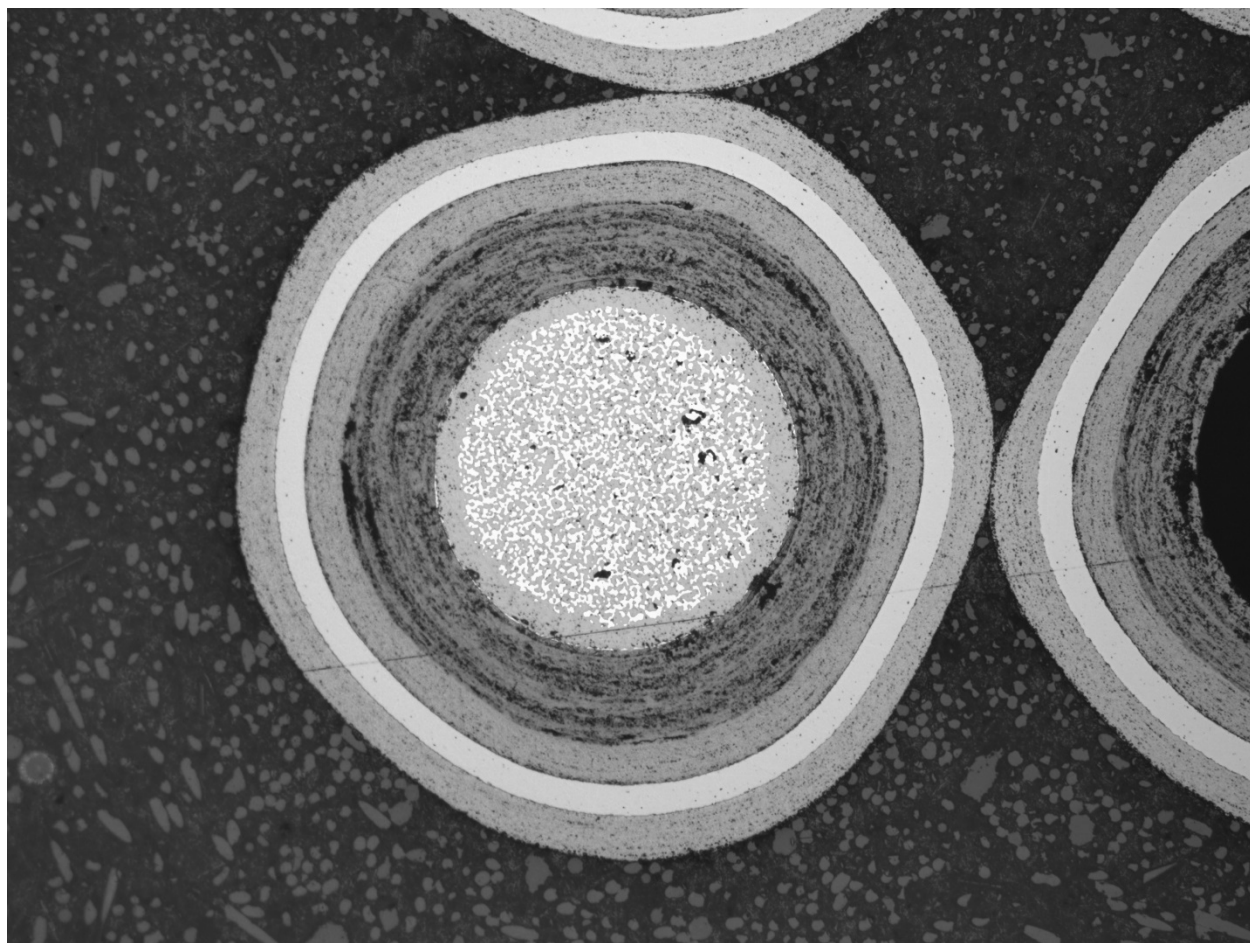


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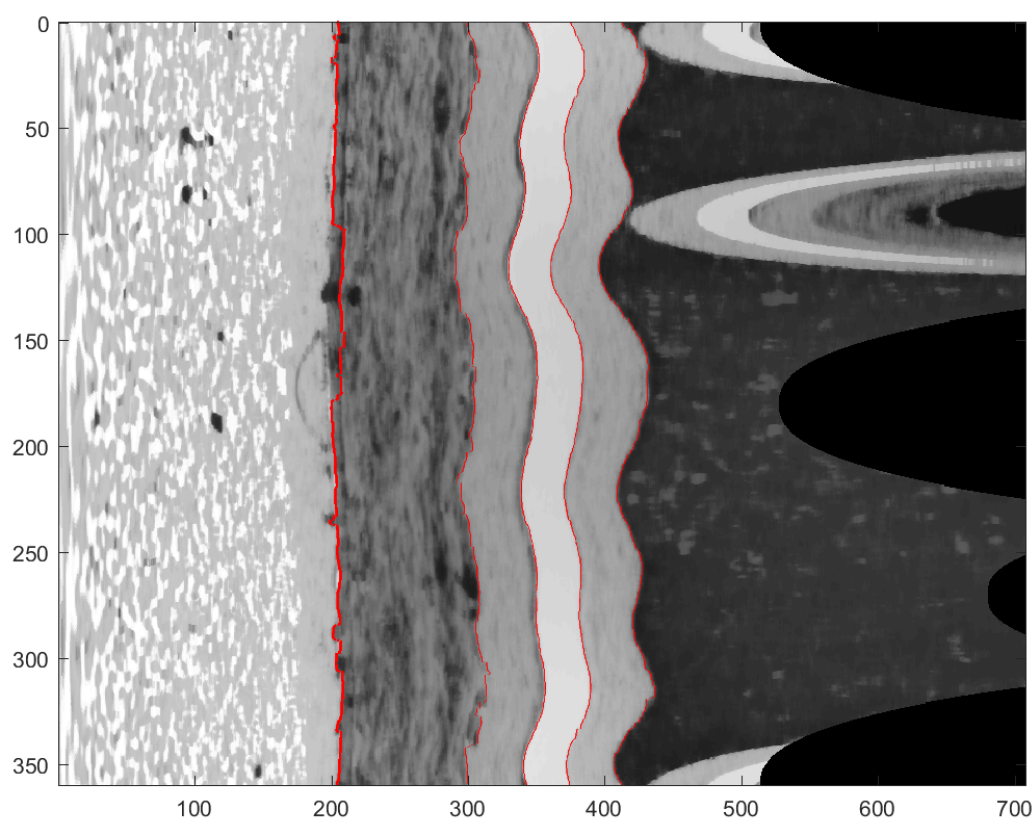


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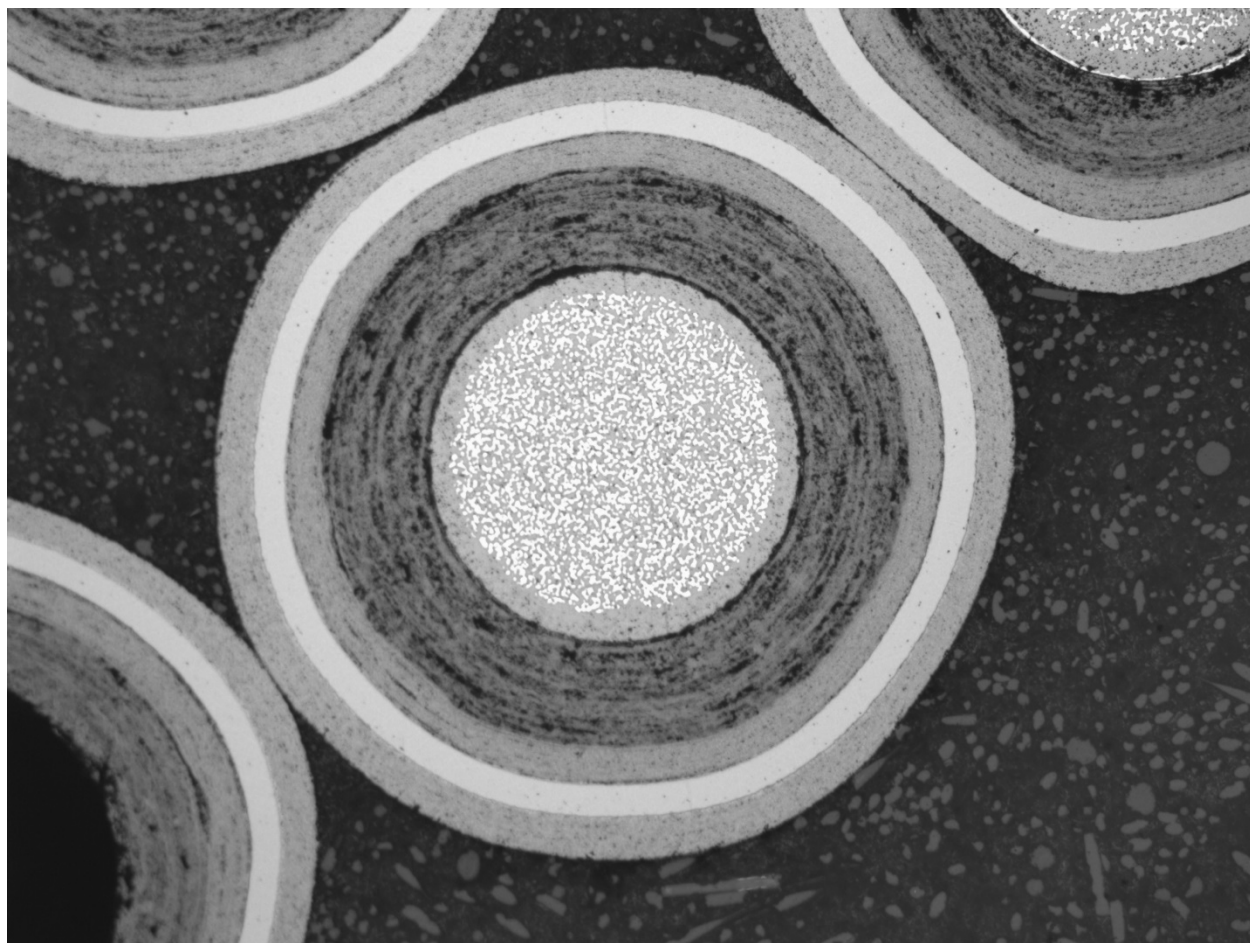




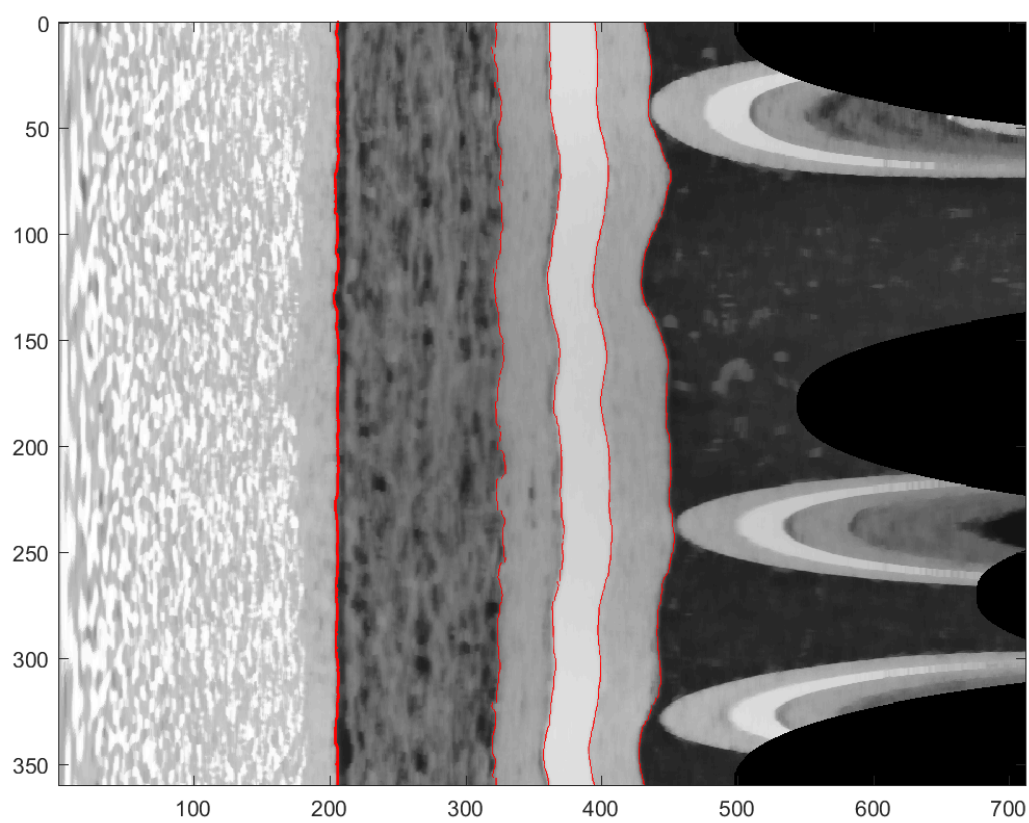
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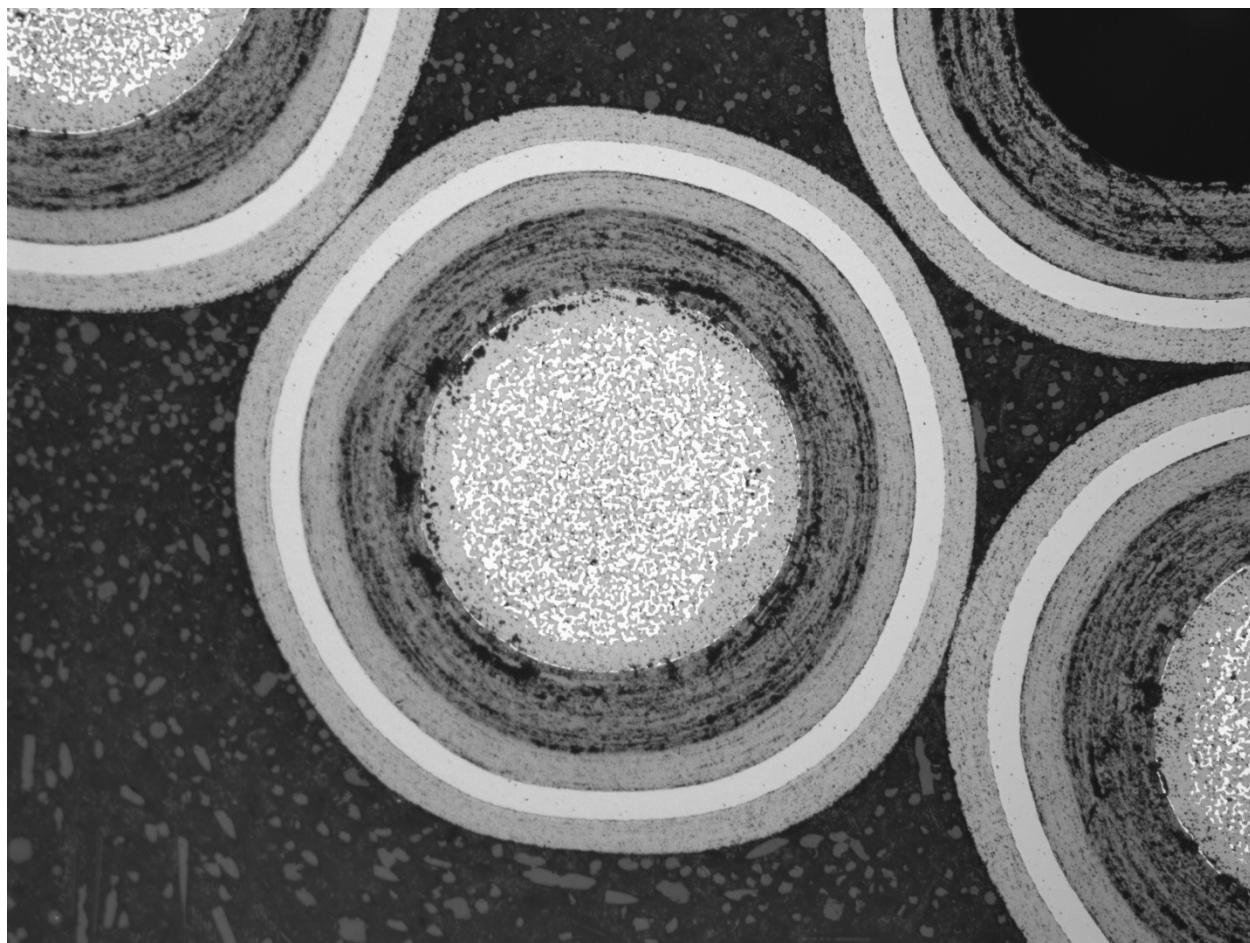
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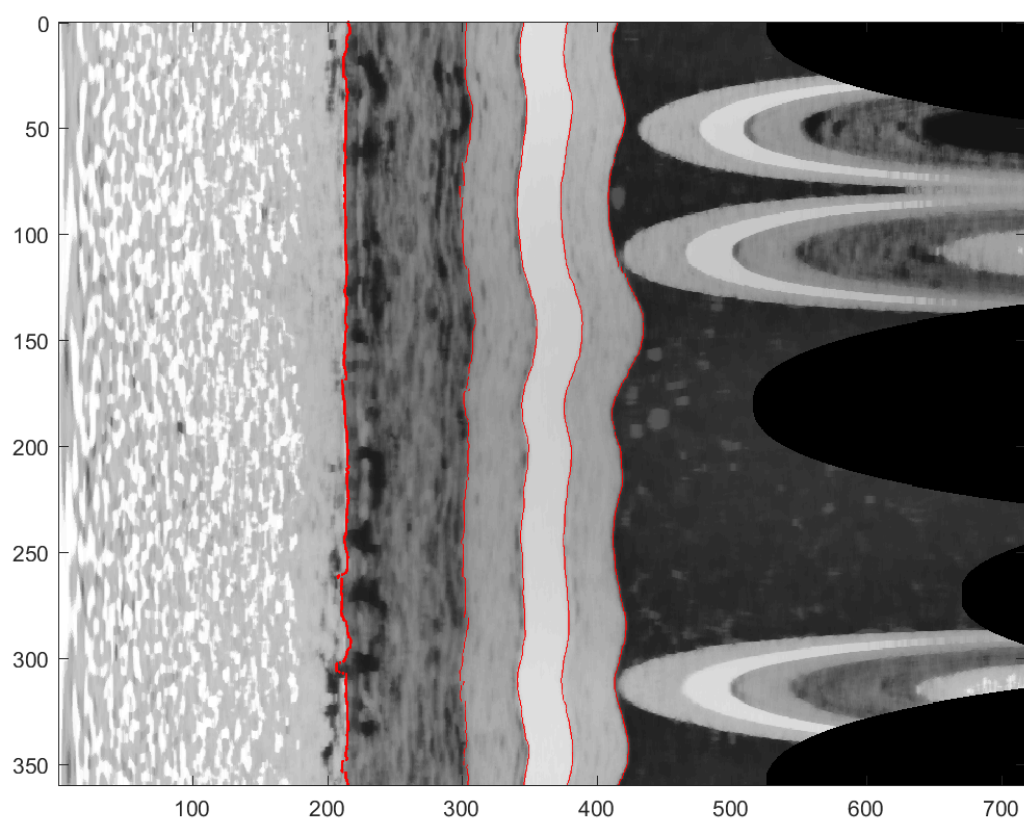
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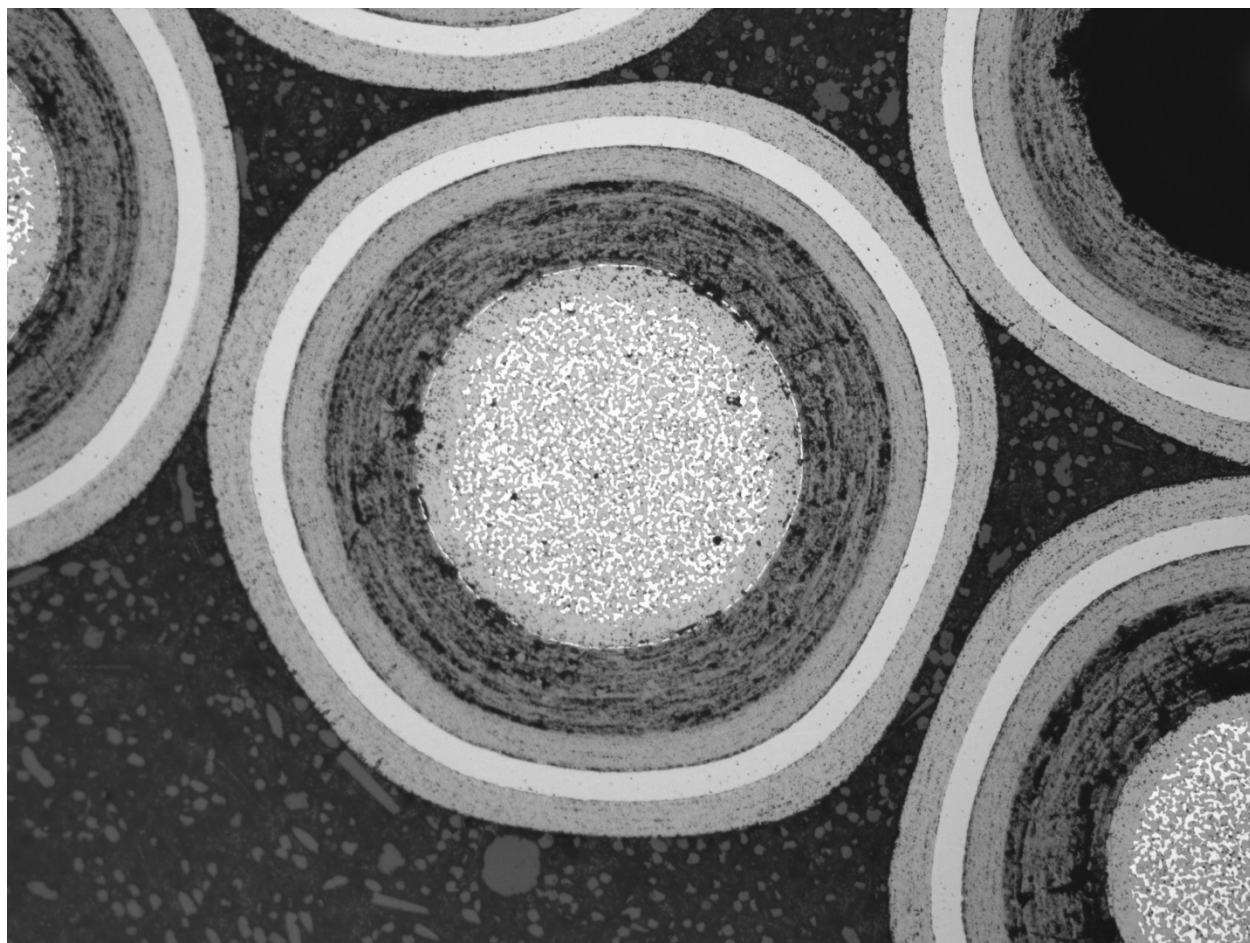


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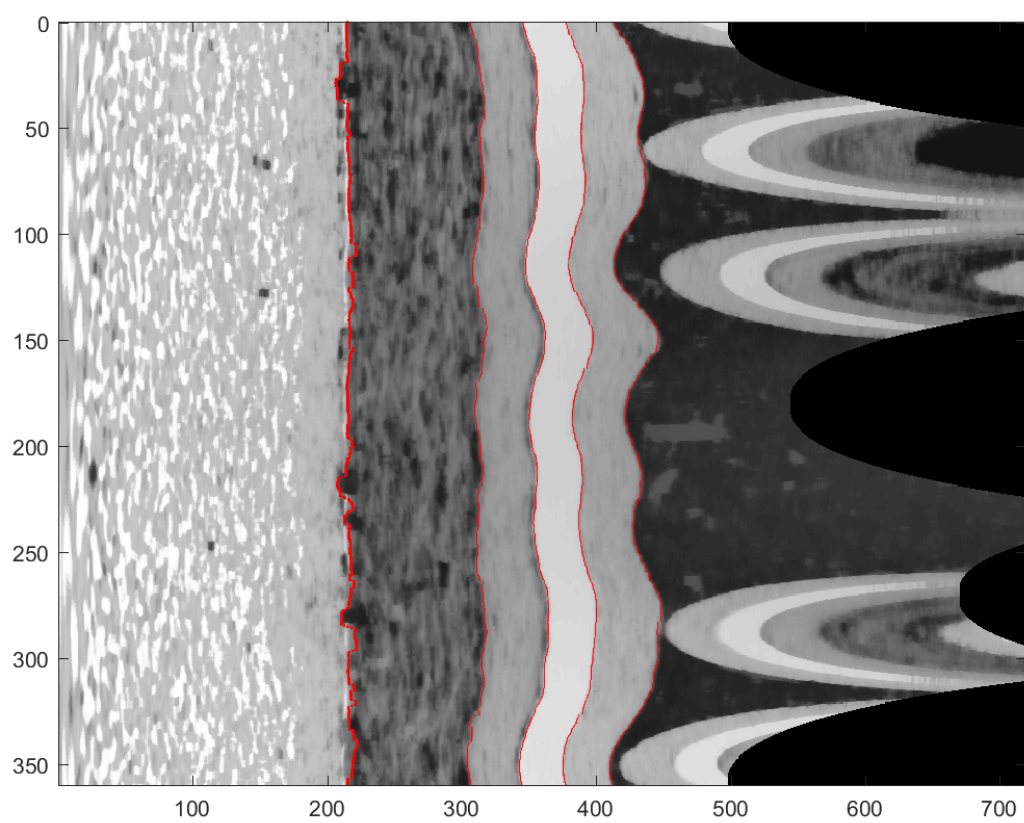


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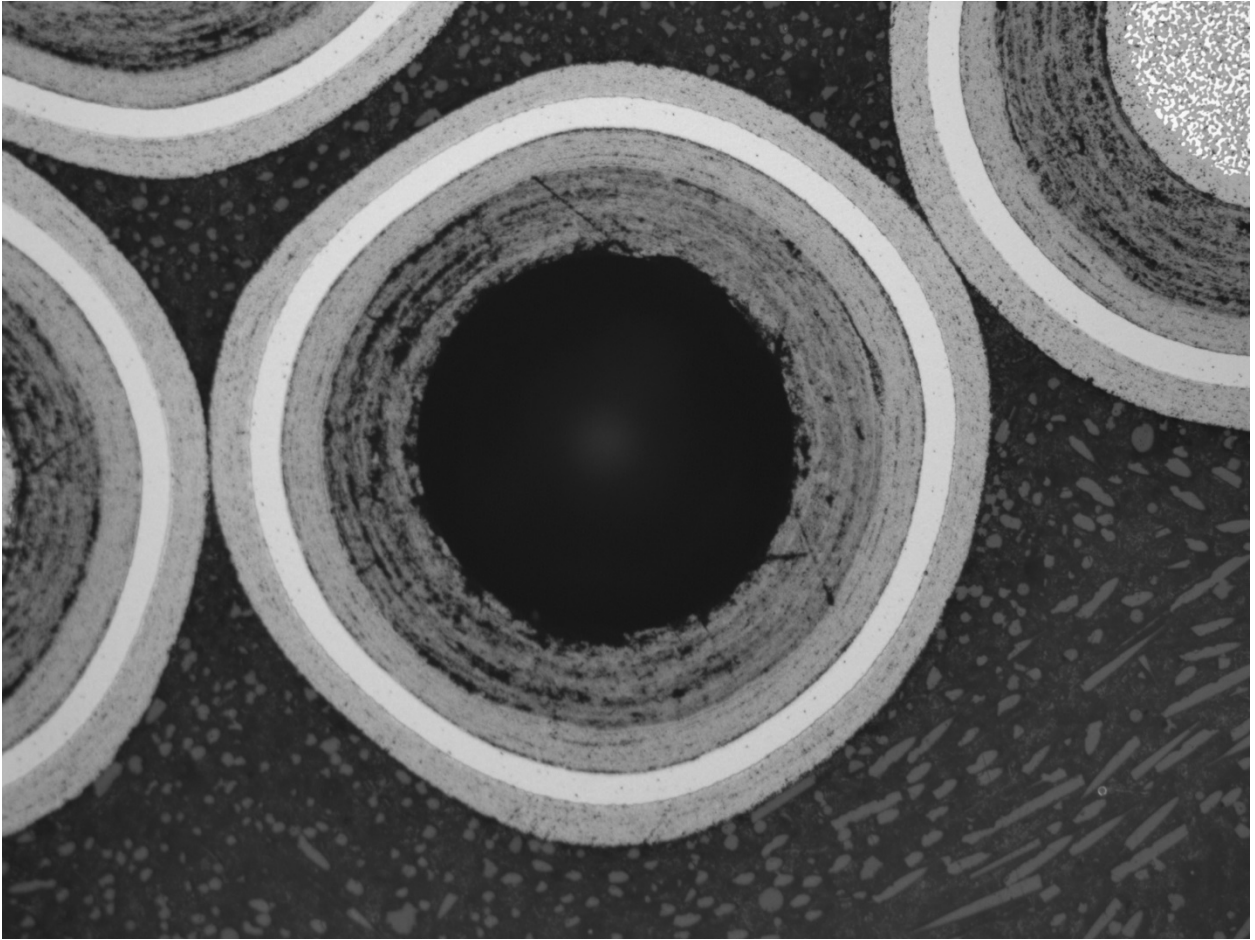




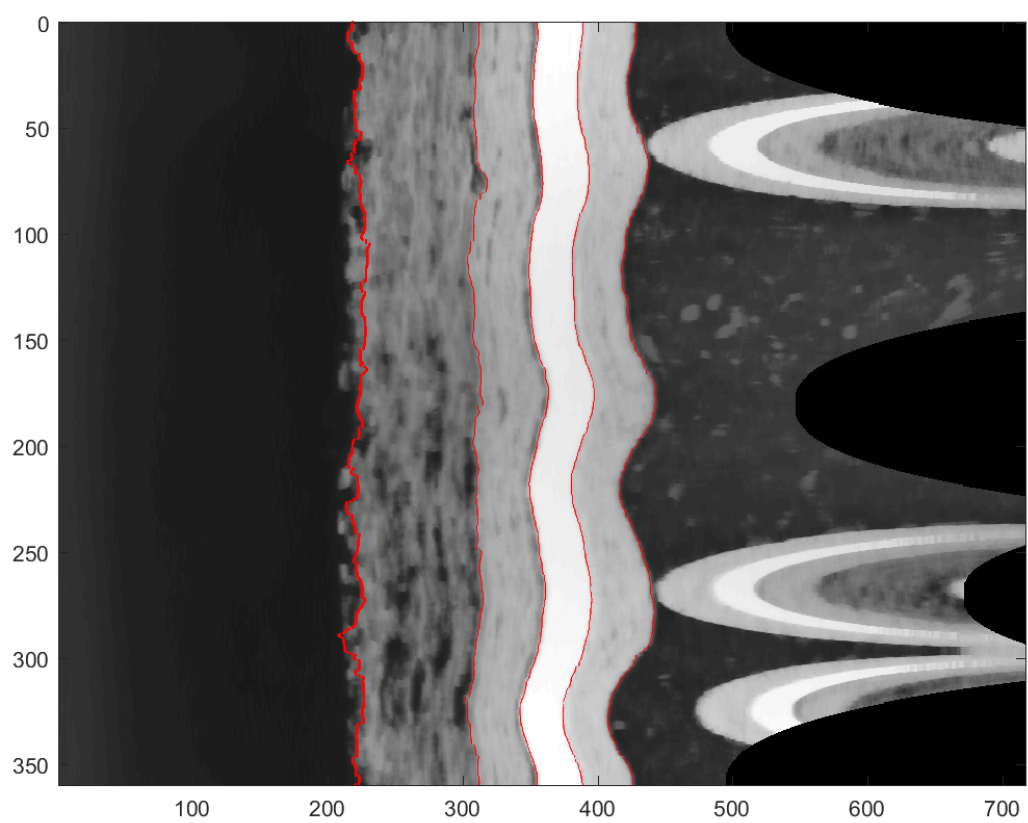
P16082301N354



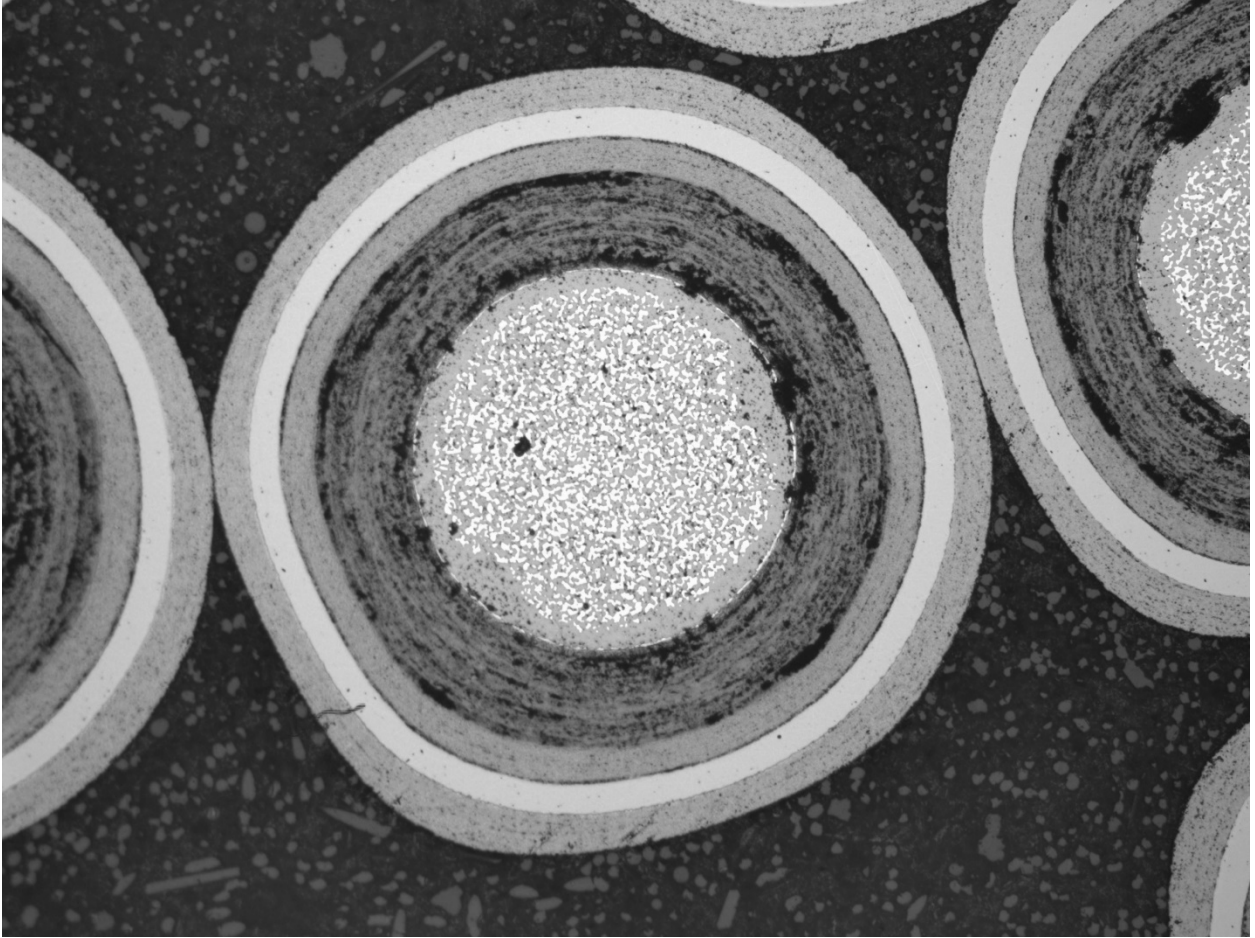
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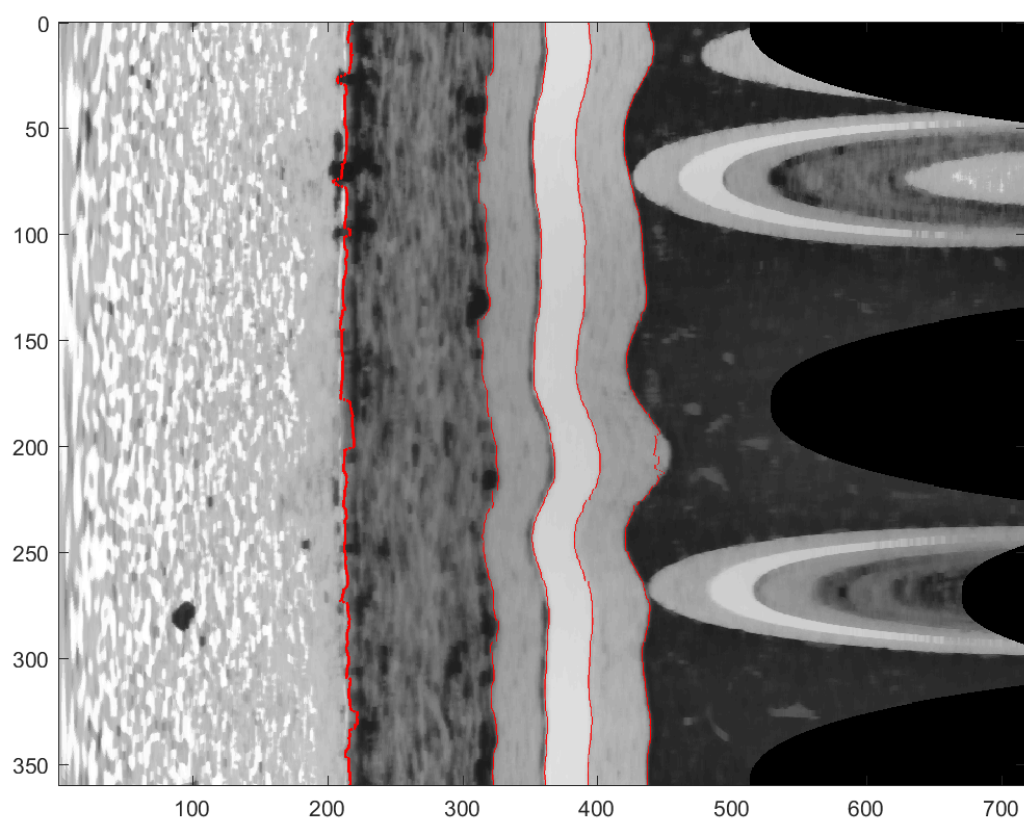
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**P16082301N355 unwrapped**

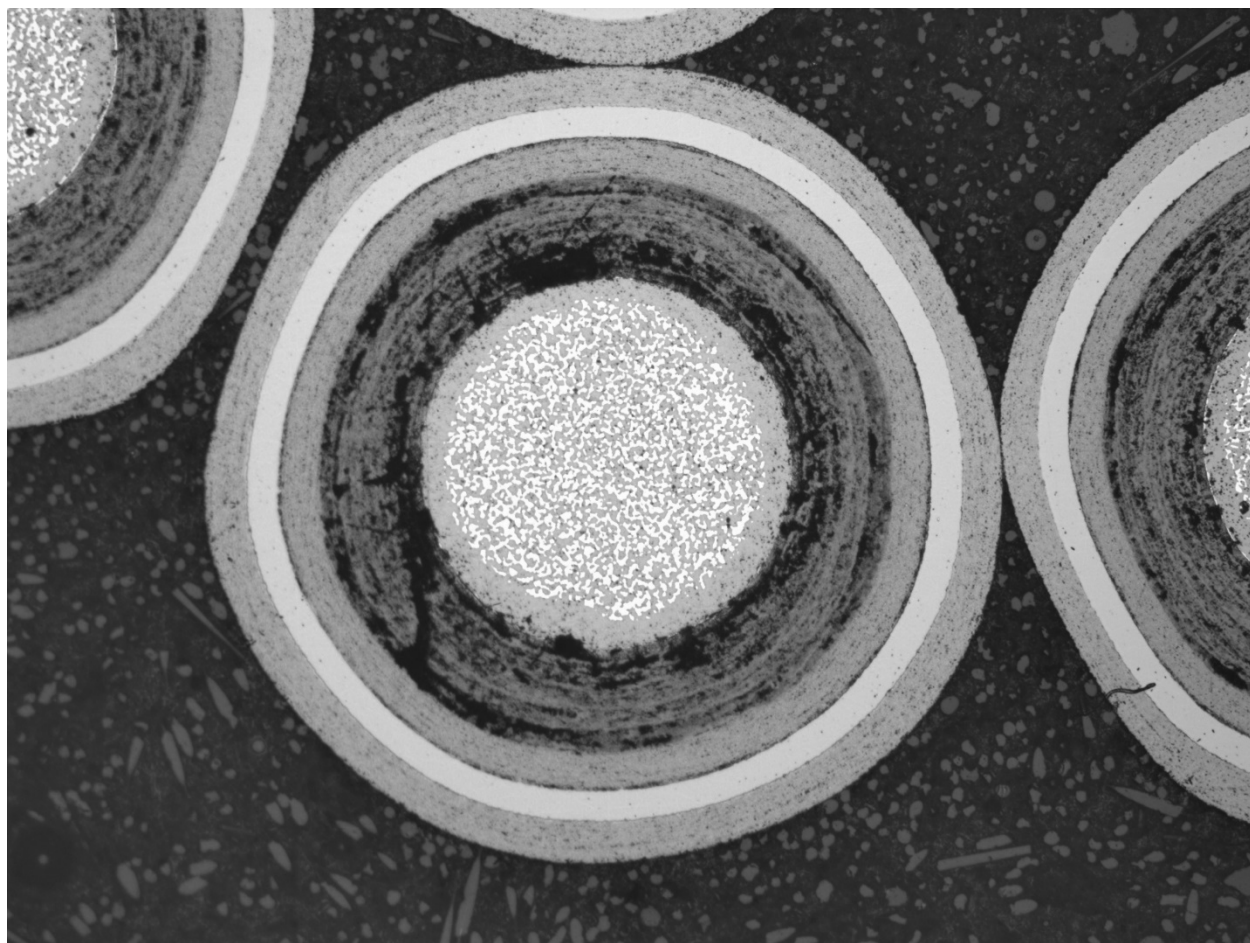


P16082301N356

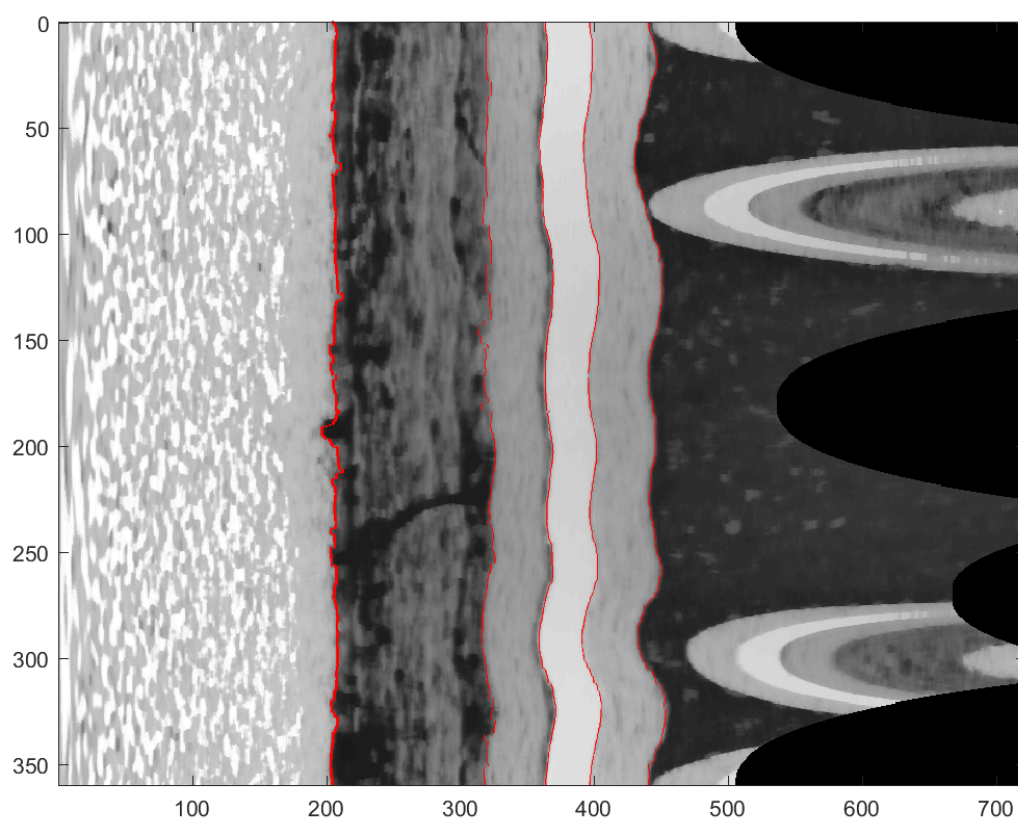


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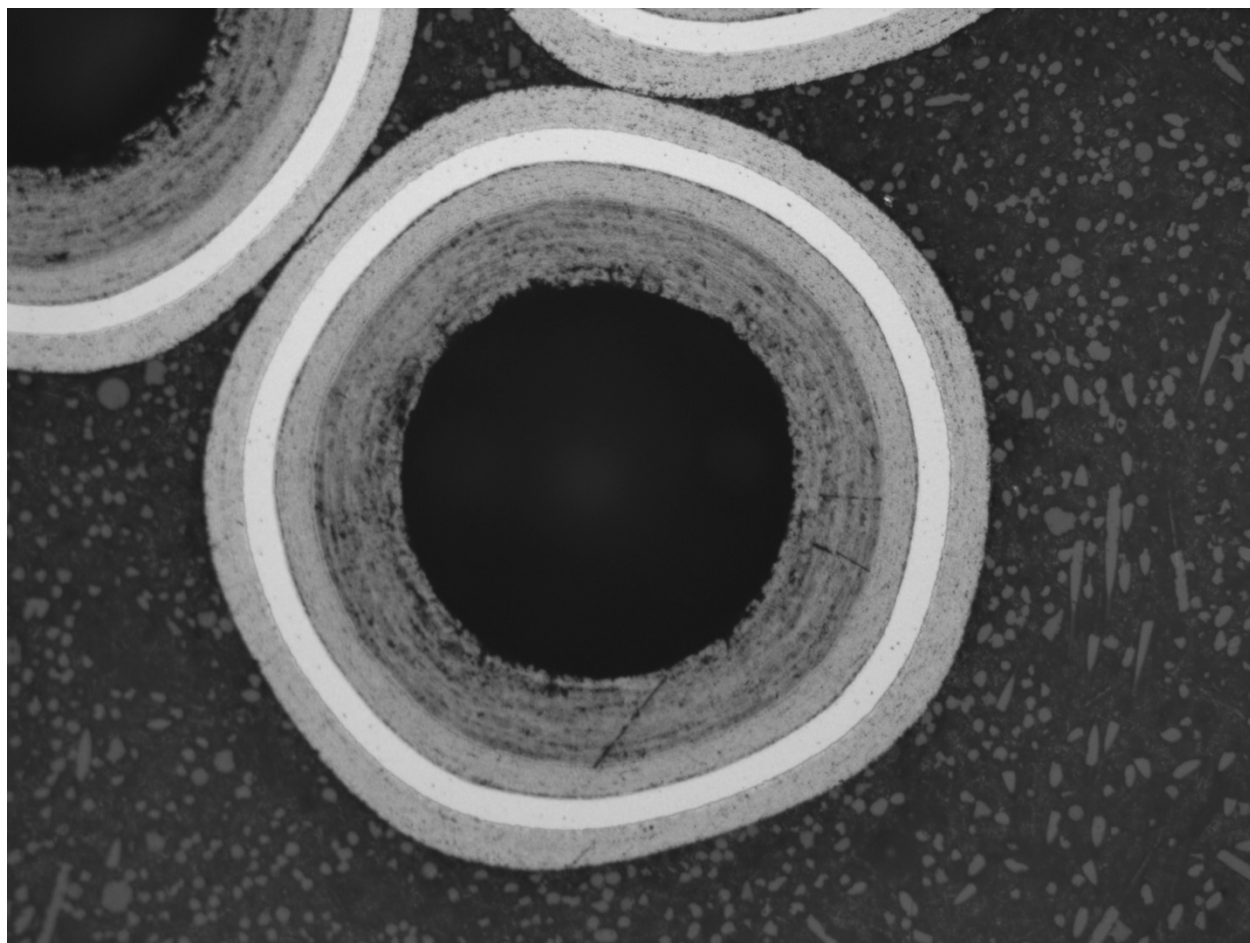




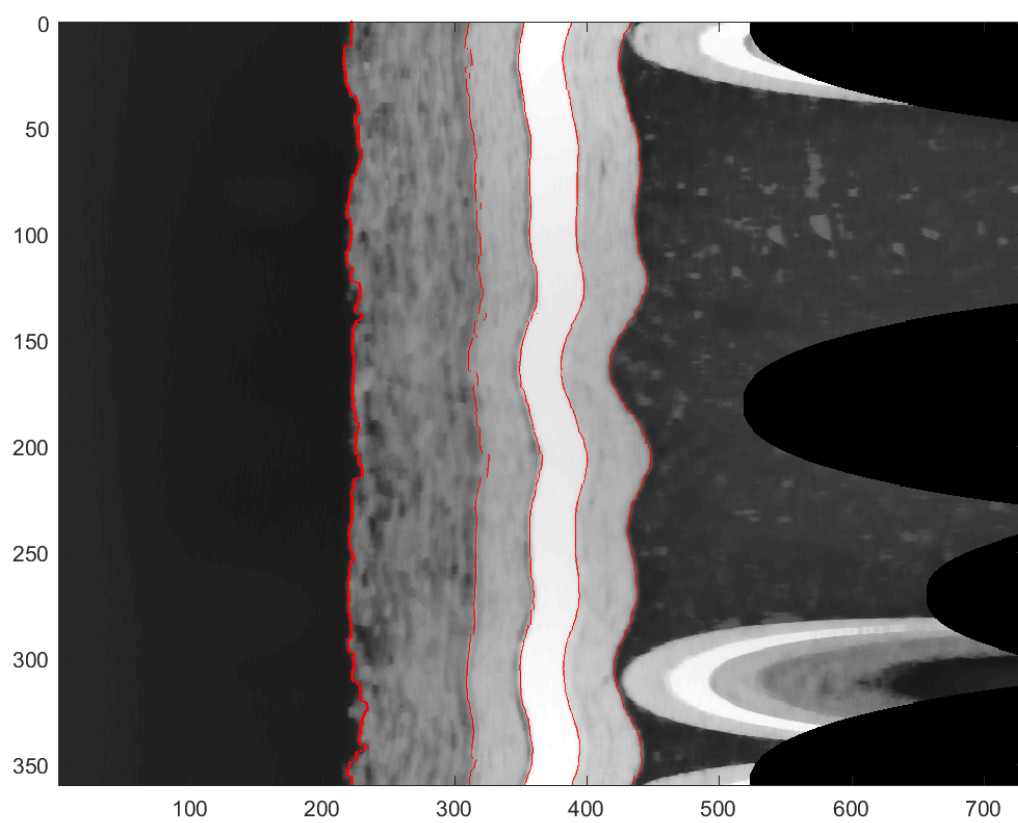
P16082301N357



**P16082301N357 unwrapped**



P16082301N358



**P16082301N358 unwrapped**

## APPENDIX B. RAW DATA FOR LAYER THICKNESS ANALYSIS

Polish-down distance and polish-down corrected mean layer thickness data are presented in the table below. Each row in the table corresponds to one set of images in Appendix A and is presented in the same order.

Polish-down Distance ( $\mu\text{m}$ )	Mean measured radius/thickness ( $\mu\text{m}$ )				
	Kernel	Buffer	IPyC	SiC	OPyC
435.9	222.7	102.2	39.1	33.5	42.1
439.3	213.0	128.6	40.2	36.2	44.6
440.4	217.5	99.5	40.1	34.2	39.3
437.5	206.1	108.3	41.9	34.9	42.8
439.3	213.8	111.1	41.0	34.6	43.3
434.3	213.8	112.3	43.6	35.3	44.1
438.0	207.8	109.1	42.3	35.0	41.6
434.7	214.9	113.3	42.0	33.4	37.3
437.3	215.2	106.8	43.0	33.6	41.7
434.3	207.5	110.6	42.0	36.0	42.3
431.7	214.2	105.4	45.2	34.7	44.7
432.1	213.0	104.0	38.2	35.9	41.5
432.5	215.7	118.2	41.0	35.4	38.4
428.7	210.9	104.0	41.3	34.0	42.0
434.1	216.4	108.9	35.3	35.2	44.5
427.5	204.9	121.5	43.4	34.8	41.9
429.3	214.4	104.0	46.3	33.2	43.2
429.2	205.1	115.8	38.1	33.1	43.5
430.9	217.7	99.5	42.1	34.8	39.4
428.1	215.2	104.6	39.9	35.4	41.4
424.9	199.4	124.1	38.0	32.8	43.6
431.7	215.2	89.8	42.4	35.7	42.6
429.6	212.0	87.6	37.6	35.8	46.3
428.2	215.0	87.1	43.9	34.7	37.7
426.9	212.7	94.3	40.0	36.2	42.0
423.4	214.4	107.5	39.7	32.1	41.7
428.7	211.2	99.1	38.4	35.4	43.1
427.4	204.7	110.0	39.8	34.8	45.3
423.1	208.6	105.3	38.4	34.4	42.2
420.5	206.3	86.2	46.3	35.8	43.5
426.5	210.3	107.9	40.8	34.3	43.1
422.5	209.9	91.1	38.5	35.2	43.7
424.5	207.8	99.9	45.8	35.3	41.1
424.5	212.4	121.7	37.8	34.9	43.3
425.7	216.3	100.1	43.7	36.6	41.2
423.3	205.3	121.6	44.0	35.0	41.6
417.7	203.9	101.9	41.0	36.3	42.0

Polish-down Distance (μm)	Mean measured radius/thickness (μm)				
	Kernel	Buffer	IPyC	SiC	OPyC
422.5	205.7	112.2	40.7	35.2	43.7
416.9	193.4	116.8	39.6	34.9	43.5
414.5	201.8	101.8	43.6	32.3	43.4
413.2	212.7	117.7	41.1	32.6	43.3
419.1	214.6	91.0	40.6	34.6	40.0
420.1	218.8	99.4	35.2	33.6	41.0
414.7	210.9	111.5	43.6	33.1	43.5
417.1	213.1	109.5	39.9	35.7	41.6
419.4	211.3	95.3	43.9	35.1	44.3
410.7	202.9	116.6	44.8	34.0	41.6
413.9	215.1	108.1	45.3	33.2	40.3
412.4	206.6	100.7	42.6	31.8	38.4
410.5	209.2	124.3	39.3	32.3	42.3
415.0	213.2	103.7	42.1	35.1	41.6
416.1	216.0	90.3	41.9	34.5	41.5
410.0	207.0	102.4	40.5	32.6	42.5
412.5	204.4	104.3	42.7	34.5	40.6
408.0	216.6	117.6	43.8	33.4	44.0
414.0	215.9	104.4	43.0	35.2	42.3
411.9	210.7	124.5	39.8	32.3	39.9
411.1	217.7	92.7	43.2	35.5	41.8
411.0	210.2	104.7	38.7	35.3	42.7
408.3	212.1	116.9	37.1	34.6	40.1
334.2	214.2	101.8	38.6	34.3	38.5
339.0	216.1	110.2	39.1	33.0	42.6
339.1			41.9	34.2	44.0
344.3			40.5	35.2	42.4
337.1	216.3	94.6	39.2	35.0	42.6
338.4	219.1	107.6	41.8	35.6	38.7
340.0	219.7	101.7	38.4	34.3	39.5
348.3	217.3	94.7	42.0	34.5	41.3
349.4	213.4	101.0	36.1	35.4	36.3
347.6	205.9	103.6	38.0	34.4	41.7
348.0	227.0	116.1	39.3	35.4	39.2
341.7	216.3	112.4	44.0	31.4	34.7
347.5	219.5	101.7	42.3	33.7	40.8
340.4	226.4	115.4	34.3	34.3	40.2
352.8	218.5	111.6	35.8	32.3	39.2
352.2	210.7	106.5	38.6	33.2	40.6
347.6	218.7	101.9	41.5	32.7	36.6
344.6	213.3	91.1	38.7	35.4	42.4
353.6	215.4	108.0	40.2	34.3	41.4



Polish-down Distance (μm)	Mean measured radius/thickness (μm)				
	Kernel	Buffer	IPyC	SiC	OPyC
356.8	215.5	108.1	43.2	33.4	41.4
343.3			42.6	34.2	41.1
352.0			39.7	33.9	39.9
345.1	210.2	90.1	37.0	35.4	40.3
347.8	218.9	91.0	38.4	34.1	40.9
350.7			34.7	35.9	36.5
351.9	211.5	94.2	40.1	34.8	37.4
361.2	207.2	106.4	38.0	34.6	40.9
351.0			39.6	34.6	39.8
357.2	209.9	99.7	42.8	34.5	39.9
356.5	199.6	112.9	39.3	36.1	42.8
359.1	204.8	96.3	39.3	35.7	40.7
349.8	214.5	87.0	39.3	35.1	38.4
351.6			42.1	37.4	39.5
364.7			44.0	34.0	42.5
356.2	213.2	98.9	37.7	34.1	37.4
359.2	201.8	107.3	38.3	33.9	38.4
351.4			44.0	33.1	39.6
361.9	207.9	90.8	41.1	37.1	41.9
353.8	209.1	91.0	36.8	34.0	41.6
365.8	218.1	110.0	35.8	33.1	38.9
364.9	206.6	109.0	42.3	34.2	42.3
361.3	200.5	108.4	40.9	33.9	41.8
363.7	200.7	125.0	37.3	35.0	40.0
370.4	211.2	119.2	41.7	34.5	42.4
359.6			37.0	36.4	40.0
369.5	216.2	104.6	39.3	33.3	39.8
362.7	202.0	91.9	40.3	36.5	41.3
359.0			42.6	34.7	44.4
357.1	203.6	108.7	39.6	33.8	43.2
362.8			38.6	35.1	38.8
358.5			36.4	33.1	39.7
365.0			39.1	34.6	38.3
356.4	213.5	92.7	40.6	32.6	40.5
368.2	214.8	108.5	40.4	35.1	37.8
370.3			43.1	34.1	41.0
374.9	213.5	113.9	39.7	31.4	40.8
361.4			39.6	33.6	42.4
364.4			39.4	35.1	39.8
363.8			37.6	33.7	39.0
374.0			41.2	34.7	41.3
358.7	213.5	111.6	39.7	33.2	39.6

Polish-down Distance (μm)	Mean measured radius/thickness (μm)				
	Kernel	Buffer	IPyC	SiC	OPyC
369.0	206.1	106.8	40.5	32.9	40.3
361.8	203.5	99.4	36.1	34.6	39.8
373.9	207.3	107.2	38.3	36.0	42.5
371.9	204.8	103.6	43.1	34.5	41.4
361.3	219.5	92.8	38.9	36.1	39.5
368.4	208.6	96.1	43.6	33.0	40.0
366.5	208.4	99.2	40.4	32.8	40.8
378.4	215.2	106.1	37.4	32.9	40.0
364.8	203.4	94.3	45.5	35.3	41.0
362.5	219.0	103.4	43.4	34.7	40.1
380.2	208.3	108.2	33.6	32.9	41.8
374.7	208.5	90.6	41.7	34.9	39.0
378.4	200.0	89.6	39.8	36.2	42.1
369.7			40.8	34.3	44.0
374.3	204.0	96.6	37.6	35.5	40.3
371.4	204.1	92.4	37.9	35.9	42.2
376.7	202.2	115.8	38.0	35.5	39.7
378.0	210.4	119.5	40.6	33.7	41.8
367.7	204.5	99.6	39.4	34.2	41.1
373.2	200.1	112.3	34.9	35.4	41.5
384.3	211.9	118.5	37.6	33.9	41.7
370.1	211.6	95.6	35.9	37.8	39.6
382.9	219.2	98.4	36.5	33.7	40.1
371.9	207.3	109.9	43.2	35.4	41.7
384.2	211.9	103.2	41.5	35.5	42.8
370.3	221.5	113.9	37.7	36.1	40.7
378.4	201.5	92.3	42.2	34.5	39.9
383.3	211.4	112.5	39.3	33.9	42.5
382.4	208.8	90.5	40.8	35.5	43.5
376.4			42.9	35.1	42.0
378.0			40.6	34.5	40.5
372.9			42.1	34.4	39.1
389.2	218.3	98.5	42.3	34.6	40.7
386.9	205.1	87.4	41.7	36.4	43.5
378.6	192.9	111.1	40.7	33.9	43.6
386.2	205.0	102.6	40.5	35.3	40.6
375.1	210.5	90.2	43.5	34.9	40.5
378.9			41.1	35.0	41.9
382.9			40.2	36.2	40.4
385.6	204.4	91.6	43.9	35.4	40.5
377.8	216.2	119.3	40.5	33.5	35.4
393.4	213.8	110.1	41.2	33.2	43.9

Polish-down Distance (μm)	Mean measured radius/thickness (μm)				
	Kernel	Buffer	IPyC	SiC	OPyC
375.5	213.0	119.5	38.0	35.5	39.7
392.8			40.9	33.9	42.8
378.0	210.2	104.6	39.7	34.7	38.1
390.7	210.8	105.4	43.6	34.7	43.0
383.6	203.5	97.3	41.0	32.6	42.8
375.9	216.8	95.6	40.7	33.9	39.3
392.0	197.2	108.8	48.7	35.1	40.0
377.2			45.0	34.8	37.7
389.4	197.5	106.4	40.0	33.7	38.0
383.4	211.9	98.7	42.9	33.5	41.2
385.9	199.0	106.5	42.9	35.7	42.0
387.6	192.3	91.0	44.0	35.6	44.7
383.8	207.5	124.8	42.3	34.3	40.7
397.7	208.7	95.2	41.2	34.1	40.6
390.9	204.3	107.6	40.7	34.1	44.0
390.3			43.3	34.1	43.6
384.4	207.1	113.1	39.5	35.0	39.4
381.9	209.5	89.3	41.7	35.7	41.9
397.1	203.3	88.3	44.9	34.5	40.4
388.9	204.4	120.0	44.1	36.4	42.1
380.8	221.0	102.8	40.2	33.8	41.5
382.1			37.4	35.3	41.6
397.0	210.2	93.9	43.1	34.6	42.5
396.0	204.5	101.5	44.6	34.1	42.2
395.0			39.7	35.6	37.8
385.1	204.5	92.5	37.6	36.0	41.0
394.1	204.6	98.3	40.4	34.2	42.9
388.0	201.1	122.3	38.6	33.8	41.2
391.0			44.5	34.3	42.4
385.4	207.9	106.2	47.7	34.6	40.6
388.4	202.0	109.1	46.0	33.6	43.1
393.1	199.0	110.8	35.3	35.8	36.6
402.6	206.0	110.4	42.7	35.3	42.2
395.6	211.9	90.7	41.4	36.1	40.0
402.1	216.6	101.2	40.3	34.6	41.5
388.8	206.1	98.5	42.1	34.8	42.1
399.4	210.7	112.8	39.9	33.8	42.2
396.2			43.6	36.8	41.0
385.6	207.5	109.8	35.6	34.3	40.8
393.9	210.8	106.8	46.3	35.0	39.6
400.9	210.2	106.7	44.3	33.5	39.7
392.8	203.1	109.4	42.8	35.5	38.5

Polish-down Distance (μm)	Mean measured radius/thickness (μm)				
	Kernel	Buffer	IPyC	SiC	OPyC
390.0	207.5	108.6	41.9	35.9	44.0
397.8	202.4	108.7	38.5	33.7	41.3
393.1	211.2	108.8	42.3	33.5	38.3
400.3			42.6	34.1	39.6
401.9	205.0	95.5	37.1	34.5	40.6
409.9	205.0	111.7	42.4	34.1	43.8
396.4	204.4	108.6	37.6	35.9	40.4
393.3	211.0	97.0	43.3	35.7	41.3
390.5	206.4	104.3	40.4	35.6	42.7
391.6	223.2	91.0	40.7	33.2	40.4
401.0	207.0	106.5	38.4	34.7	43.1
404.6	212.5	107.7	43.7	33.7	41.3
406.5	214.6	92.4	40.4	34.7	41.1
407.6	212.4	101.4	45.2	33.7	43.5
396.9			43.9	34.6	41.2
398.9			45.0	35.4	43.9
403.7	200.5	130.2	41.4	33.5	39.6
394.7	202.9	105.6	41.1	31.8	39.1
402.7	203.6	101.7	44.0	34.7	41.0
405.1	213.7	98.2	41.9	35.0	43.1
411.5	204.8	113.5	43.5	34.0	40.8
400.9	211.8	105.0	42.7	35.8	42.6
407.4	219.1	89.5	40.4	36.2	38.2
402.8	207.0	95.9	35.8	35.0	41.5
394.7			44.8	34.2	42.3
395.8	216.2	124.1	41.8	34.7	40.4
401.2	207.7	94.0	39.5	34.5	40.5
405.7	211.0	109.1	41.7	35.7	41.1
411.3	197.5	119.4	40.9	34.8	42.7
409.5	220.2	91.7	42.1	34.5	38.6
410.6	207.9	95.3	35.8	35.5	39.0
401.4	205.4	105.8	38.7	35.1	38.4
415.0	211.0	111.7	39.7	34.0	40.4
407.2	211.0	104.1	38.6	36.7	39.7
409.8	201.9	107.7	37.4	33.3	42.0
411.7	199.1	115.0	39.5	33.6	41.0
407.4	207.7	113.2	38.4	33.4	41.9
416.3	212.9	97.9	44.6	33.3	40.9
403.1	219.6	104.2	44.7	34.9	42.5
416.5			41.7	33.0	40.6
410.7	211.4	124.5	46.7	37.4	41.0
403.0	200.7	112.6	40.1	32.8	42.9

Polish-down Distance (μm)	Mean measured radius/thickness (μm)				
	Kernel	Buffer	IPyC	SiC	OPyC
406.1	202.0	108.4	41.3	34.4	41.3
402.5	208.8	113.7	39.2	35.1	40.7
413.4	216.7	101.6	40.4	35.6	41.1
415.6	207.7	107.7	43.0	34.6	42.6
412.0	194.4	133.0	36.9	33.2	40.1
407.2	210.3	110.4	37.7	34.9	43.3
414.4	210.1	101.5	37.9	36.1	41.4
410.2	213.8	106.8	42.4	33.7	39.9
412.0	207.3	98.3	45.4	33.5	40.1
420.8	209.4	110.7	39.0	31.8	41.3
403.9			43.1	33.5	42.4
417.4	209.9	97.8	42.1	33.1	45.7
407.9	203.8	101.0	40.3	35.4	39.4
421.3	213.2	111.5	43.0	33.8	41.2
407.3	212.4	131.0	39.7	33.1	43.9
410.8	212.0	99.8	43.7	35.4	42.9
406.7			40.9	34.9	38.3
418.0	215.6	96.9	38.6	35.7	43.5
411.8			38.1	34.4	44.8
419.1	204.7	107.4	44.8	33.6	41.1
410.7	211.3	104.9	38.3	34.3	42.1
414.6	202.2	121.6	41.6	33.9	38.3
416.5	199.4	101.6	37.4	35.5	41.2
417.6	204.7	95.4	44.6	35.2	42.3
412.0	213.1	111.3	43.3	33.5	44.2
422.9	208.6	129.0	42.0	33.2	40.3
421.1	213.6	90.2	41.2	35.3	43.2
421.0	203.9	118.1	38.8	35.2	36.2
415.2			39.3	33.8	38.6
419.1	209.2	99.8	42.9	34.0	42.5
424.0	215.5	105.0	42.5	32.9	43.0
413.0	222.4	88.6	44.7	35.5	43.6
418.4			41.5	34.7	39.3
428.1	206.6	138.7	43.5	32.4	42.5
416.4	210.5	97.4	39.6	34.8	41.1
431.0	220.6	105.7	43.7	32.4	45.1
426.9	214.8	99.4	40.6	32.1	40.0
420.8	211.9	102.5	42.9	33.1	41.8
430.2	211.1	98.4	42.3	34.7	43.1
430.4			38.3	34.6	39.3
423.5	210.8	115.1	37.1	33.9	42.7
430.8	205.5	119.3	38.5	32.8	41.0

<b>Polish-down Distance (μm)</b>	<b>Mean measured radius/thickness (μm)</b>				
	<b>Kernel</b>	<b>Buffer</b>	<b>IPyC</b>	<b>SiC</b>	<b>OPyC</b>
424.3	212.8	103.0	39.6	32.8	39.4
434.7	215.2	111.6	44.3	34.1	45.0
437.5			42.2	32.8	39.9
428.2	204.9	97.1	43.1	32.3	41.7
440.7	205.6	118.9	41.2	34.3	41.8
433.2	214.2	89.4	43.0	32.5	38.8
435.8	216.2	96.8	42.0	33.7	42.2
442.4			44.1	32.8	40.0
440.0	214.1	105.7	39.3	32.3	41.3
439.2	206.4	114.2	44.4	33.2	44.7
446.1			41.0	34.3	43.4





