Understanding Bi-2212 Strand-Rolled Filament Structure Using Deep Learning Methods

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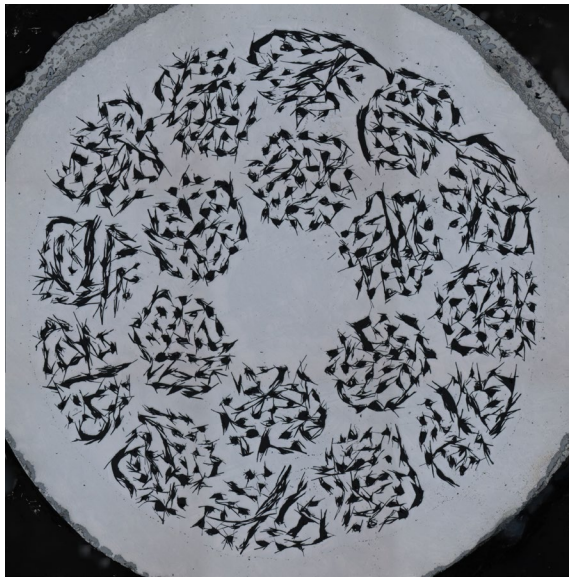
Motivating Questions

- Broadly interested in automating and economizing quality control techniques for SC wire/tape production & characterization
- This study is attempting to quantify Bi-2212 filament bridging in composite strand-rolled Ag/2212 PIT wires
- Extent of filament bridging is difficult to quantify by traditional image analysis techniques, so we built a semantic segmentation machine learning model to perform this task in an automated fashion
- Model was then applied to wires used in cabling studies at LBNL
- Rolled Green Wires were also analyzed to investigate model results



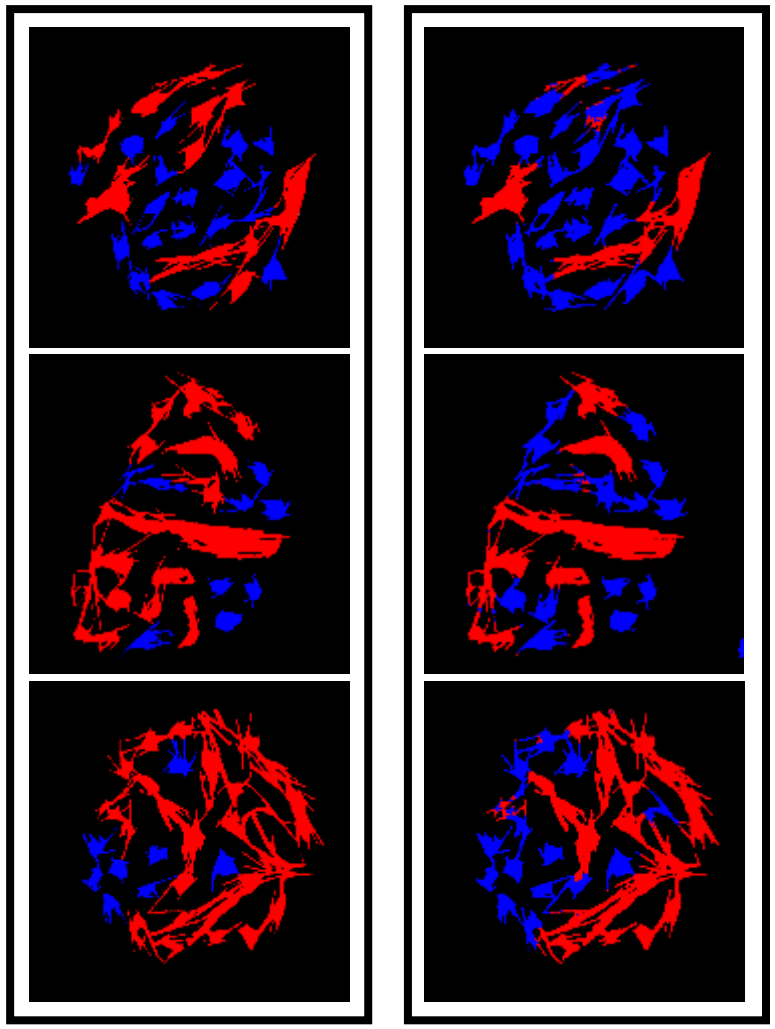
Sample Set

- Green Wires (provided by LBNL to UWEC):
  - pmm101111
  - 2 Round Wires (0.8mm Diameter)
  - 1 Rolled to 0.72mm Diameter
  - 1 Rolled to 0.57mm Diameter
- 4 Wires Total

- Heat-Treated Wires (preparation and imaging by ASC/NHMFL):
  - pmm101111
  - 1 Round Wire
  - 2 Rolled to 0.72mm Diameter
  - 2 Rolled to 0.69mm Diameter
  - 2 Rolled to 0.67mm Diameter
  - 1 Rolled to 0.636mm Diameter
  - 2 Rolled to 0.62mm Diameter
  - 1 Rolled to 0.58mm Diameter
  - 1 Rolled to 0.55mm Diameter
- 12 Wires Total

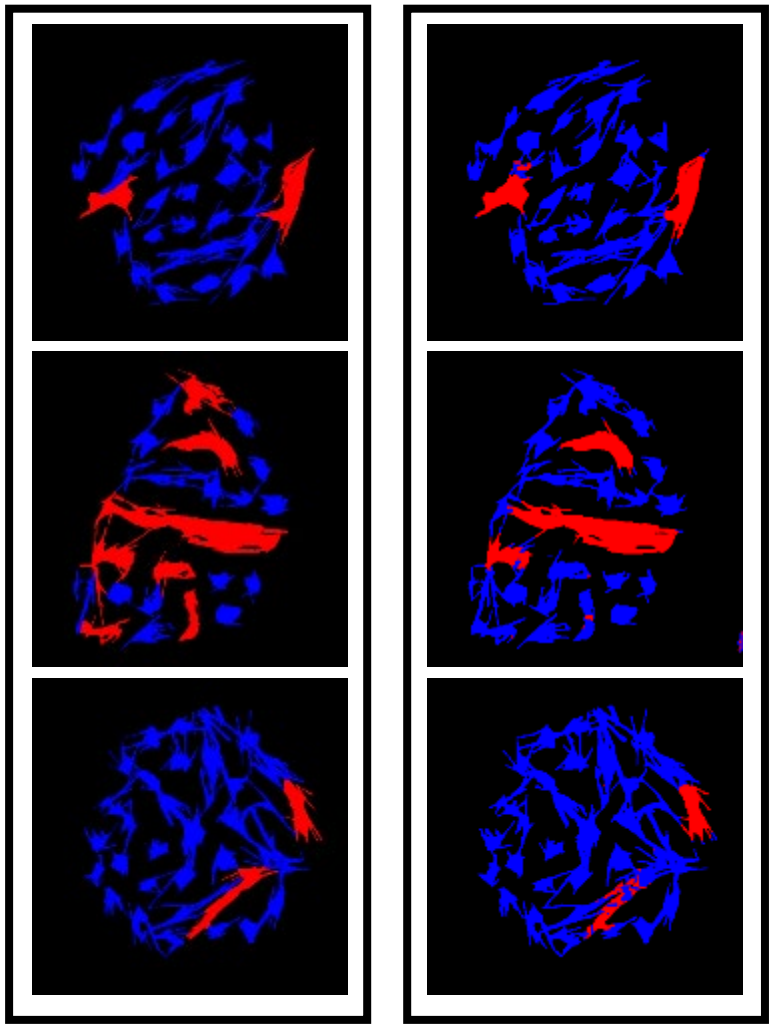
- Heat-Treated Wires (provided by LBNL to UWEC):
  - pmm101111
  - 1 Rolled to 0.72mm Diameter
  - 1 Rolled to 0.69mm Diameter
  - 1 Rolled to 0.67mm Diameter
  - 1 Rolled to 0.636mm Diameter
  - 1 Rolled to 0.62mm Diameter
- 5 Wires Total

Model results



Ground truth Model prediction

Liberal definition of conjoined



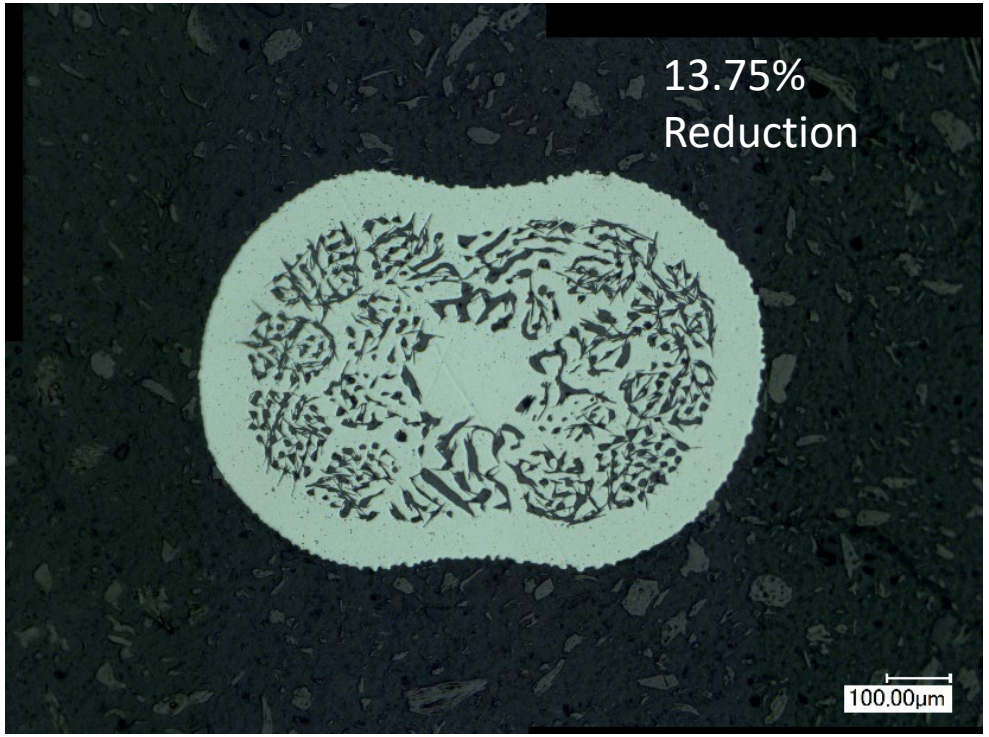
Ground truth Model prediction

Conservative definition of conjoined

- The model is able to intuitively classify filaments as conjoined or individual (no outliers) under both levels of sensitivity on test image.
- Overall pixel accuracy of **94-95%**
- Filament accuracy of **73-75%**

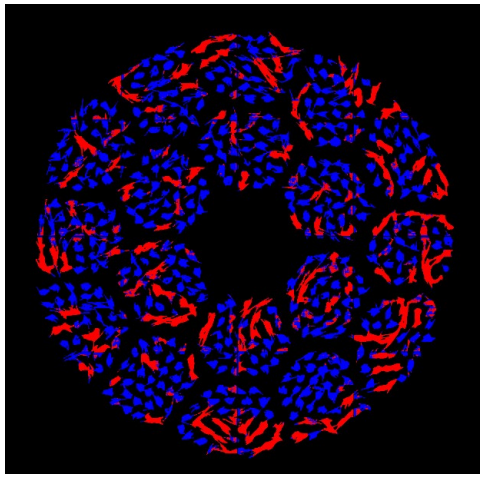
Applying the Model

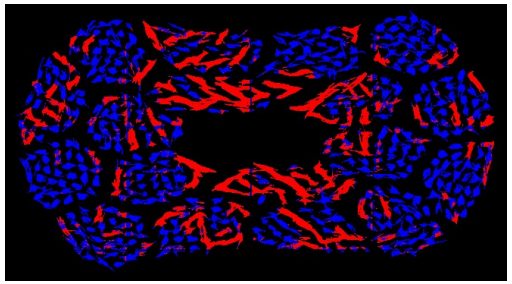
- To utilize our model, we acquired additional image data using rolled wires from Lawrence Berkeley National Laboratory (LBNL)
- Using the model, we made predictions on the rolled wires
- These predictions were then analyzed to test if the model could be used in a practical manner beyond its training data and applied to real problems

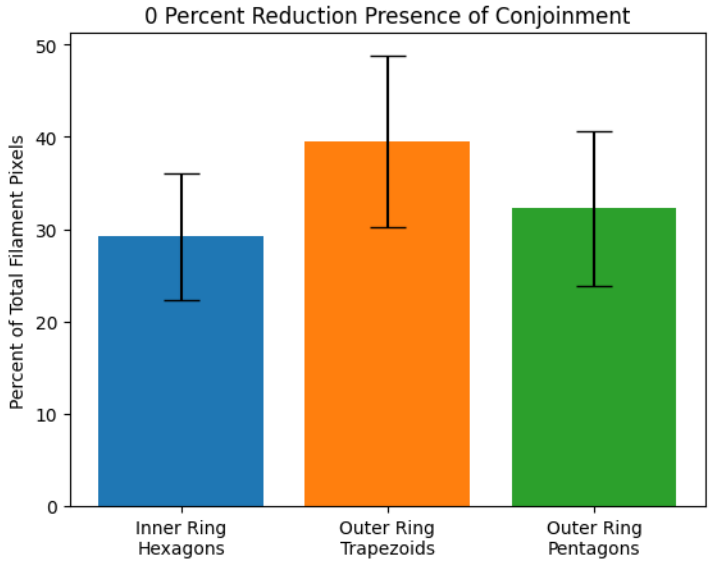


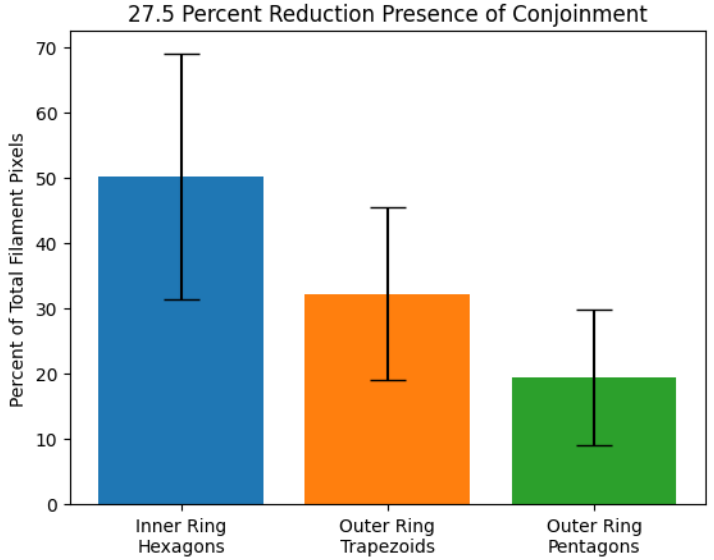
Applying the Model

- The model can identify conjoined filaments in this data set with similar accuracy as the original data set
- Strand rolling does not increase the overall prevalence of conjoined filaments (30-35% conjoined at all levels of rolling >15%)
- However, rolling does consistently increase the prevalence of conjoined filaments in the inner ring of sub-bundles
- This may in turn impact current distribution characteristics in the cable



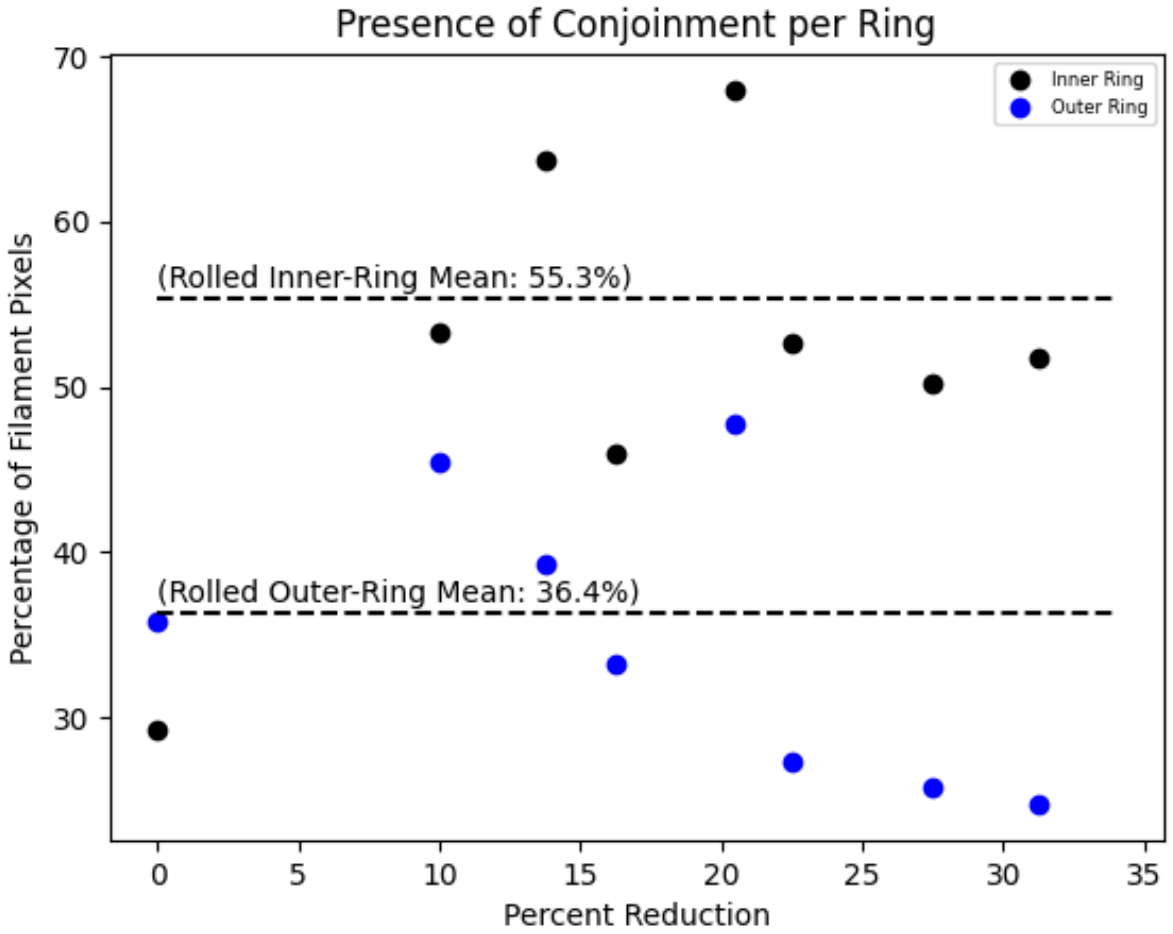






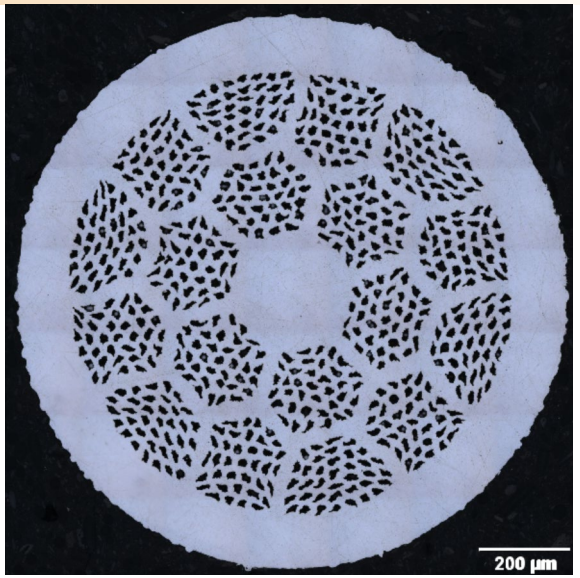
Applying the Model

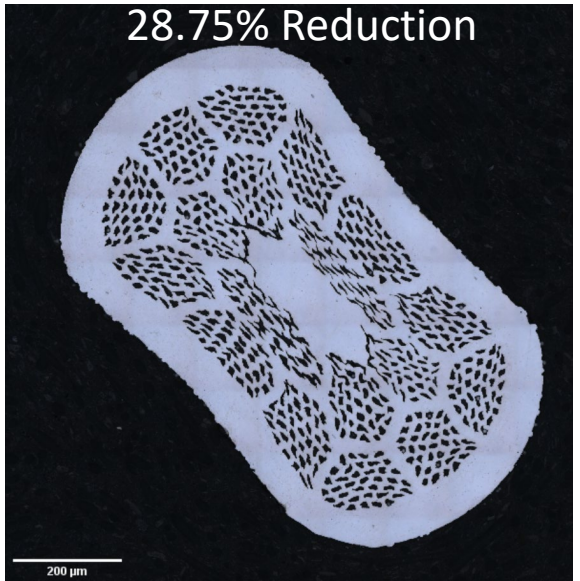
- To gain a quantitative understanding of how strand rolling affects conjoinment, we made predictions with our model on multiple heat-treated wires, and collected our results
- We notice that, except for the round wires, rolling increases the prevalence of conjoinment by over 15% on average
- Further, we notice that overall, the outer ring filaments do not experience significant changes in conjoinment, but do have consistently less conjoinment due to the rolling process



Understanding the Results

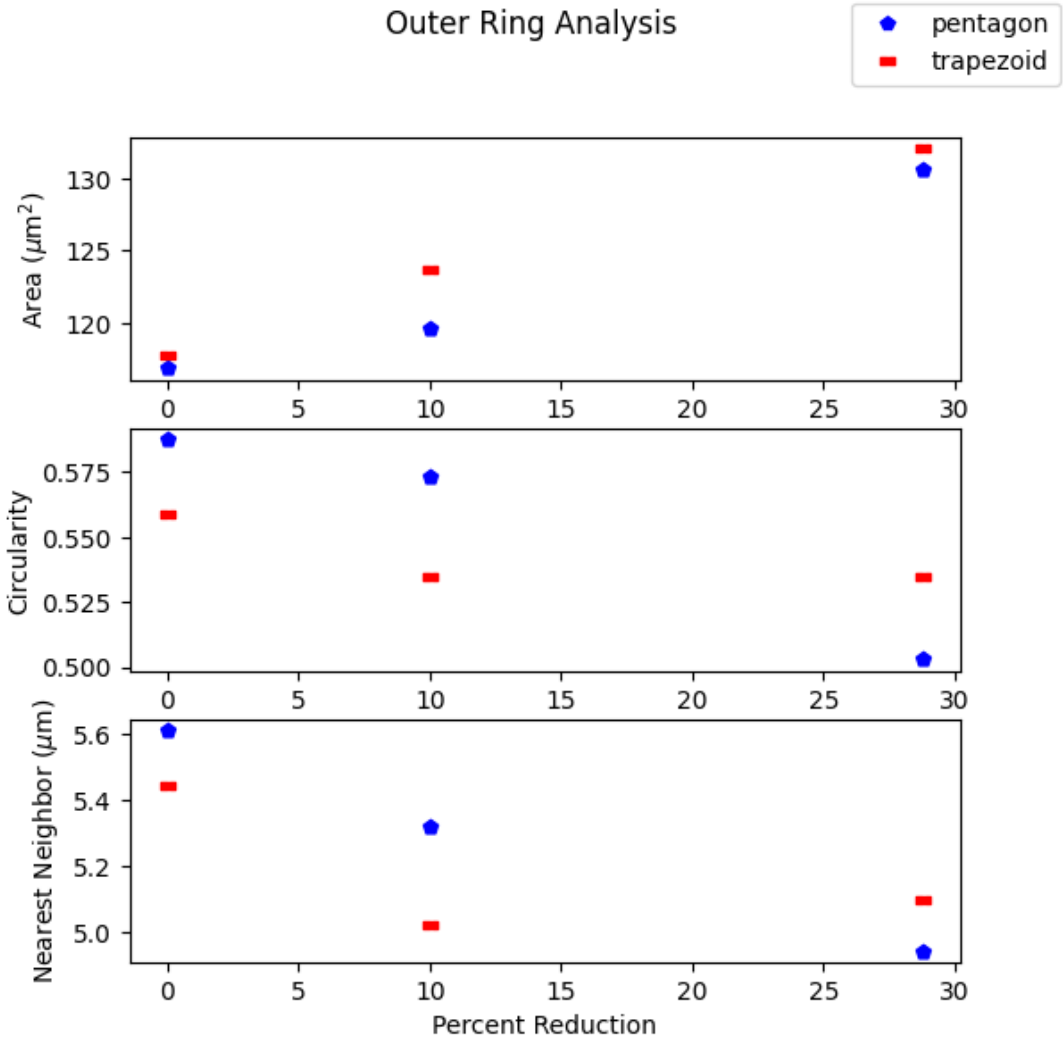
- To investigate the cause of increased conjoinment in rolled inner ring filaments, we examined a set of round and rolled unreacted green wires from LBNL
- Each filament in the wires were then analyzed for nearest neighbor, circularity, and area data using the open-source software ImageJ





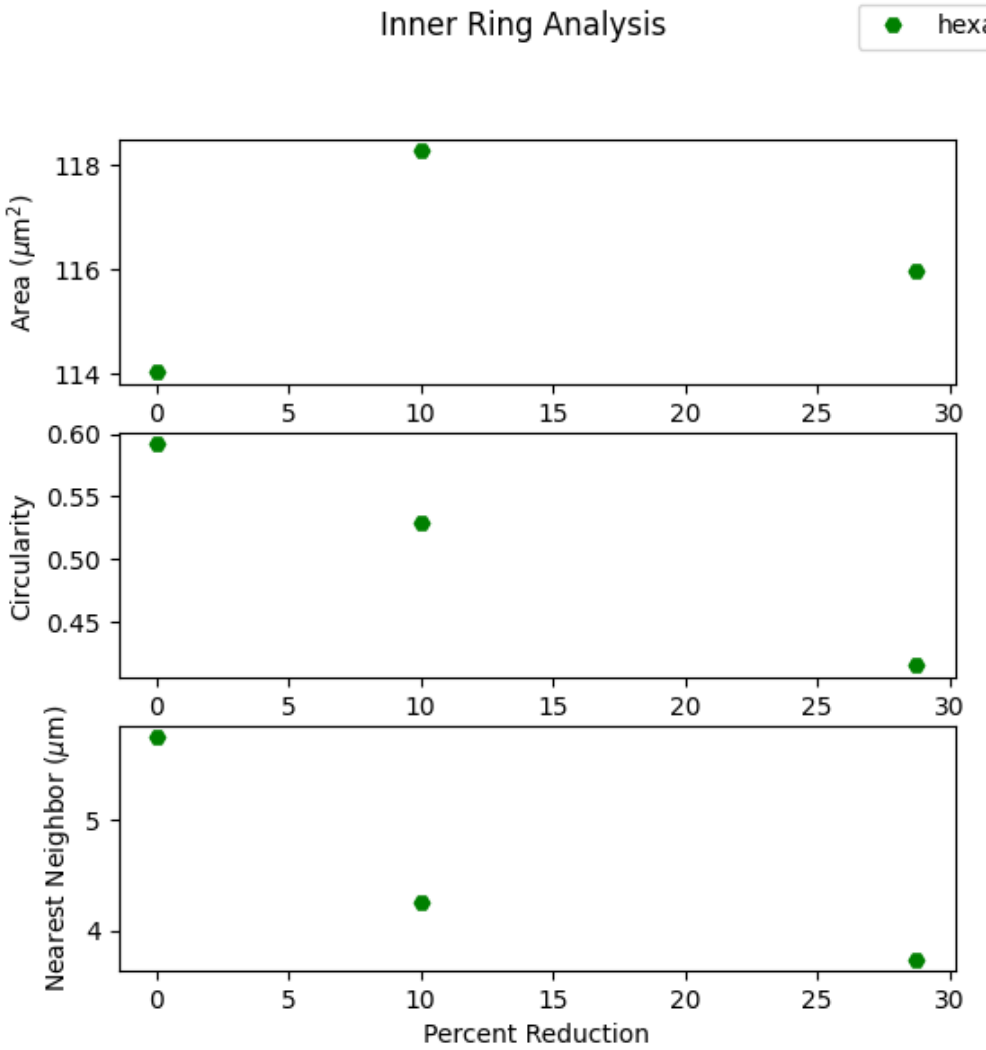
Green Wire Analysis

- Our Analysis of 4 different Green Wires found that outer ring filaments have increased area of nearly 20 μm^2 but only modest changes in circularity and nearest neighbor
- We suspect this is caused by the lateral expansion of the outer ring during the rolling process
- This would demonstrate why the model detected a decreased presence of conjoinment in the outer ring filaments



Green Wire Analysis

- Conversely, the inner ring filaments have at most 4 μm^2 while significantly lowering their circularity and nearest neighbor by as much as 20% each
- The implication is that the inner ring filaments are becoming warped and distended due to the rolling process
- This would explain why the model detected increased conjoinment in the inner ring



Where do we go from here?

- We have a working model and are ready to use it on additional data sets
  - The model somewhat underpredicts the presence of conjoined filaments, but so far simply increasing the dataset size has not solved this problem.
  - Some remaining work to package the code for deployment…we are still doing a few steps manually
- We would like to begin correlating these results to I_c or losses…does MDP have a database of 2212 wire performance? It's easier to take pictures (if needed) than to do I_c tests.
- We would like to assess variation along the length of the conductor, similar to our green wire filament homogeneity work (see Jewell talk at LTSW 2023)
- We would like to explore whether LBNL's synthetic data approach could be used to simplify training and extend this model to other categories of problems
- Your feedback would be welcome on any of these efforts…

Questions?

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