

Carbon Fiber Evaluation *by Image Analysis*

Carbon fiber is a thin, fibrous material with a micro graphite crystal structure composed of carbon atoms. The atoms are aligned parallel to the long axis of the fiber, making it extremely strong for its size. Carbon fibers are classified into three classes: PAN-based for those made of polyacrylonitrile resin, pitch-based for those made of oil or coal pitch and rayon-based for those made of textile material. They also have different properties depending upon the precursor used to make the fiber. Carbon fibers are rarely used as-is but as reinforcement and/or functionality of composite materials made with resin, ceramic or other materials. They are used in such diverse areas as structural components (aircrafts, automobiles), sporting goods (golf shafts, bicycle frames), or as construction material (reinforced concrete). The quality of the fiber, its strength and resiliency, are factored by its precursor, and are important quality control issues. Determining its mass per unit of length, its volume, or even its general cleanliness or any residual binding material are important and directly affect its properties and its final use as a composite. Optical microscopy is ideally suited for this task.

Sample Preparation

To properly analyze the physical dimensions of carbon fibers with optical microscopy we need to have uniform dispersion on the slide. Too many on a slide and it becomes impossible to measure overlapping fibers in clusters; too few fibers on a slide and the results become skewed and non-reliable. With a good dispersion overlapping fibers can be identified as individuals for measurement with current image analysis software.

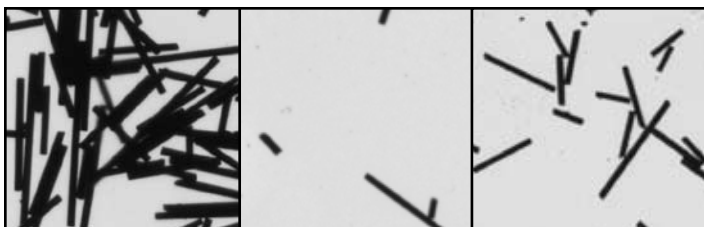


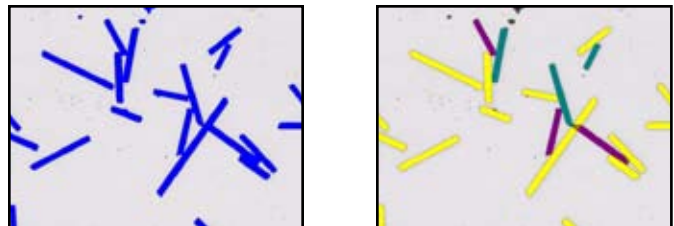
Image Analysis

For the purpose of this analysis we used a Clemex Vision PE image analysis system equipped with a black & white camera, a microscope fitted with transmitted light and an motorized stage. The microscope used 2.5x to 10x objectives. The stage, the microscope and the camera were all controlled by the Clemex Vision PE software.



The light intensity must be adjusted properly and the sample must be in focus under all magnifications.

The first step is to binarize the black areas with an Auto Gray Threshold. In this case we binarized with a blue bitplane. The bitplane allows us to easily obtain the features we want to measure. Some artifacts may be binarized in the process but these are easily eliminated. Since some long fibers have a good chance of overlapping or of being part of a cluster, isolating them with a separation tool allows us to retain the fibers for statistical purposes instead of eliminating them. Using the Split Long Objects command, we now have two or more different identifiable objects instead of one cluster.



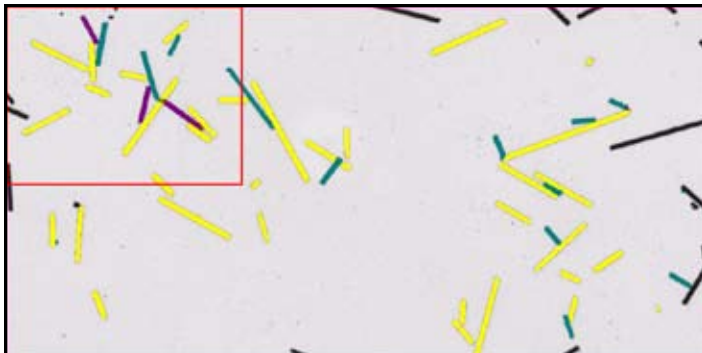
Left: Binarization onto a blue bitplane. Right: Fiber separation with the Split Long Objects tool.

Long objects also have a tendency to spill out of the frame of view. For that reason we implement a Guard Frame that decreases the working area and acts as a safety buffer. The automated stage is automatically set to move exactly the size of the Guard Frame. Since each binary feature is identified by an ID point on its top-most left pixel, those with the ID point inside the Guard Frame will remain binarized for this frame, while those with the ID point outside the Guard Frame won't be binarized until they are identified in the next frame.



Guard frame (red) implemented and long objects with ID points outside the guard Frame are rejected.

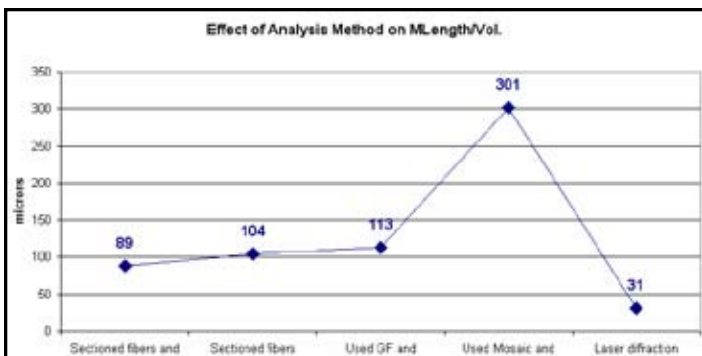
The challenge here is to get the greatest number of valid fibers to be recognized and analyzed. The best way to achieve this is to stitch adjacent images together. Using the Mosaic command from Vision PE, the software controlled motorized stage moves from one Guard Frame to the other, stitching together all relevant fields into one single large image. Once the Mosaic is completed; detection, separation, and cleaning of artifacts can easily be performed. The final result shows a significant decrease in sectioned fibers when compared with our original field of view.



Example of a 6x6 Mosaic image.

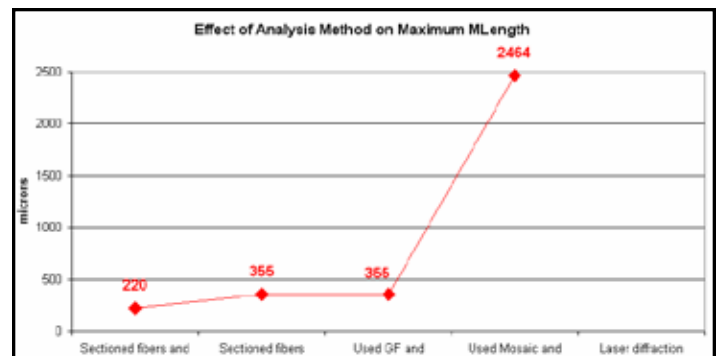
As for measurements, usually Ferets are used to calculate length and width, the former being calculated by the longest feret and the later being calculated with the shortest feret. But what of irregular shapes? In cases like these we should, and did, use more appropriate measurements: Main Length and Mean Width. For carbon fibers, two more measurements were extracted: Volume Estimate and Elongation (or Aspect Ratio), these last two were calculated based on the first two measurements.

Having dealt with sectioned and/or overlapping fibers, having enlarged the analysis area by using a mosaic image, and having used appropriate measures, how do the results fare with other analysis methods? Below is a graph showing the value of the Main Length/Volume Estimate reached by analysis method.



As can be seen, when fibers are eliminated because they are sectioned and whether agglomerations are eliminated or separated, the difference in value is minuscule. Laser diffraction, one of the most common analysis methods, fares no better. Only when the Mosaic image is used do we have meaningful and accurate results.

In the second graph, below, we compared the same analysis methods with the Maximum Main Length found in the sample. The line graph looks similar to the previous one, showing that the use of a Mosaic image increases the likelihood of finding and recognizing long fibers. And again, while laser diffraction is the most common analysis method for fibers, it cannot recognize the largest carbon fiber, rendering it useless for this kind of analysis.



The only inconvenience this method has is that fewer fibers are measured compared to laser diffraction. But that is overshadowed by the fact that optical microscopy gives real length, distributions, and maximums, and allows for visual validation and identification of the longest fibers. Also, width, elongation and other measurements are available.

Summary

For carbon fiber evaluation with optical microscopy to produce reliable and consistent result we first need to prepare samples with sufficient fibers to analyze. Then, with the help of reliable microscopy and imaging equipment, we must separate overlapping fibers using specialized tools. Using a guard frame to deal with fibers sectioned by the field of view, we then use a mosaic to help us view and count large fibers outside of the guard frame. The use of correct measurements, such as Main Length, Elongation, Volume, and others is essential. Once all relevant information needed for statistical value is taken, visual validation can be made if desired.

