FlowCam®

# Fiber Analysis with Flow Imaging Microscopy

## INTRODUCTION

Geometry can play a crucial role in the performance of fibers in different applications. Shape factors that influence performance include length (i.e. size of the longest dimension of the fiber), width (i.e. size of the shortest dimension), and curl. Despite the importance of fiber geometry, many conventional particle sizing measurements struggle to accurately capture the morphology of these particles. Volumetric-based particle sizing methods such as laser diffraction and Coulter Counters assume particles exhibit spherical geometry and only report equivalent spherical diameter (ESD) measurements. Manual microscopy, the primary method used for measuring fiber length and width, is low-throughput and labor-intensive to perform.

Flow imaging microscopy (FIM) instruments like FlowCam are an automated, high-throughput alternative to manual microscopy for fiber analysis. VisualSpreadsheet® software acquires and analyzes images of fibrils, providing automated measurements of not only fiber length and width but also fiber straightness and curl from particle images similar to those obtained via manual microscopy (Figure 1). As FIM instruments capture fiber images in a flowing fluid, this technique offers much higher throughput than manual microscopy. These features make FlowCam an ideal instrument for rapid, automatic fiber analysis.

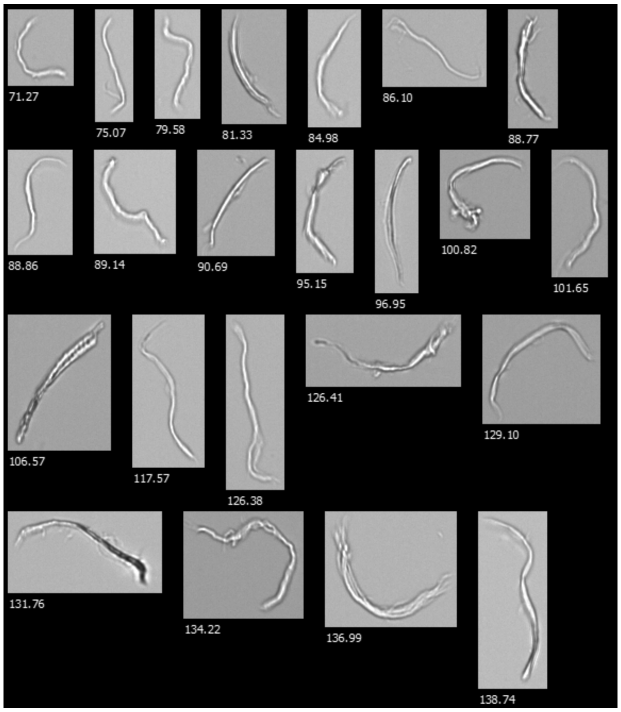



**Figure 1.** Example FlowCam images from a cellulose microfibril sample as seen in VisualSpreadsheet

## FIBER MEASUREMENTS IN VISUALSPREADSHEET

Most particle imaging systems use Feret measurements to determine the length and width of particles. Feret measurements involve finding edges on opposite sides of a particle that are parallel to each other and measuring the distance between these edges. The shortest Feret measurement is reported as particle width, and the longest is reported as particle length (Figure 2). These Feret measurements are recorded as the "Length" and "Width" parameters reported by VisualSpreadsheet. While these measurements are accurate for symmetric and straight particles, Feret measurements dramatically undersize the length and oversize the width of curved particles.

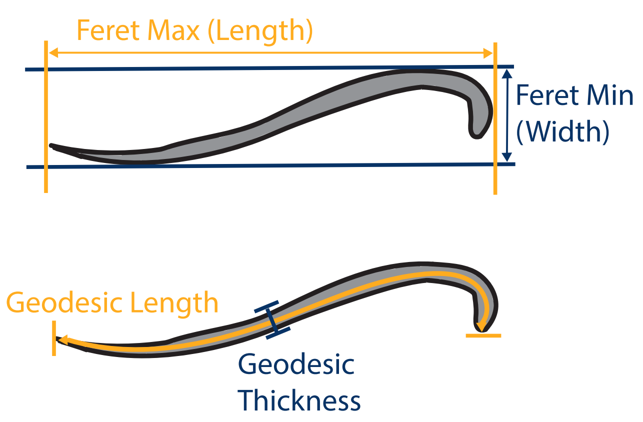
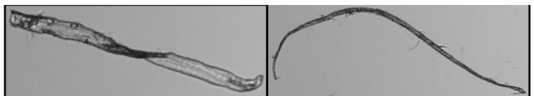



**Figure 2 (right).** The calculation of length and width using Feret measurements (top) and of geodesic length and thickness (bottom).

VisualSpreadsheet also records Geodesic measurements of particle lengths and widths. Geodesic measurements account for the arcing of particles like fibers, thus providing a more accurate representation of fiber length and width (Figure 2). In VisualSpreadsheet, these fiber measurements are reported as geodesic length and geodesic thickness.

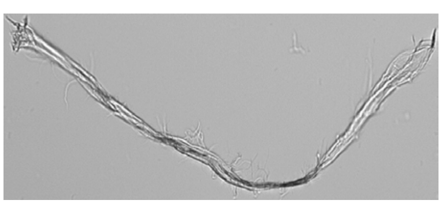
Figure 3 shows a comparison between these measurements for a straight fiber and for a curved fiber. Reported values for length (Feret) and geodesic length of the straight fiber are relatively similar, as are those for width (Feret) and geodesic thickness. When these values are compared for the curved fiber, the length (Feret) measurement is much lower than the geodesic length measurement, and width is a much larger value than the geodesic thickness measurement. While the length (Feret) measures the long-axis distance covered by the particle, the geodesic length factors the curvature of the particle into its reported length and is thus more accurate. Similarly, the geodesic thickness is more accurate as it primarily accounts for the width of the particle and not the short-axis distance covered by the particle.



| Property Name | Value (µm) | Value (µm) |
|---|---|---|
| Geodesic Length | 691.9 | 1075.8 |
| Geodesic Thickness | 23.8 | 13.7 |
| Length (Feret) | 640.0 | 723.5 |
| Width (Feret) | 37.2 | 253.3 |
| **% Difference Feret vs. Geodesic measurement** | | |
| Length | 7.8% | 39.2% |
| Width/Thickness | 43.9% | 179.5% |

**Figure 3.** The straight fiber on the left exhibits relatively low percentage differences when comparing length to geodesic length (blue) and width to geodesic thickness (yellow). The curved particle to the right shows a larger % difference between length and geodesic length (blue) and between width and geodesic thickness (yellow), with length (Feret) measurements being underestimated and width (Feret) being overestimated.

Other fiber measurements available in VisualSpreadsheet include fiber straightness and fiber curl. Fiber straightness is the ratio of length (Feret) to geodesic length. Higher straightness values indicate better agreement between the Feret and geodesic length measurements, corresponding to straighter particle geometry. Fiber curl is calculated by dividing geodesic length by length (Feret) and subtracting one. A particle with a fiber curl of zero is perfectly straight and increasing curl values indicating higher degrees of curling. Figure 4 shows fiber measurement data for a curved wood fiber with a relatively high fiber curl value and relatively low fiber straightness value.



| Property Name | Value |
|---|---|
| Fiber Curl | 0.9 |
| Fiber Straightness | 0.5 |
| Geodesic Length | 1277.7 µm |
| Geodesic Thickness | 18.5 µm |
| Length | 667.5 µm |
| Width | 242.4 µm |

**Figure 4.** Fiber measurements for the particle shown at left. This particle exhibits a relatively high value for fiber curl and low value for fiber straightness, given its ~90° bend. Note the large difference between geodesic length and length (+610.2 µm) and between geodesic thickness and width (-223.9 µm) due to particle curvature.

## USING FIBER MEASUREMENTS TO EVALUATE SAMPLES

In applications where fiber morphology is important for quality control of fibrous materials, VisualSpreadsheet can be used to build and save custom filters that automatically report counts and concentrations of particles matching a particular specification. For example, if fiber straightness is of concern, pre-built filters can automatically report a percent of fibers that meet or exceed a user-defined fiber straightness threshold.

Figure 5 shows data for custom value filters created for bleached softwood cellulose microfibrils at a specific stage of the refining process. For this example, at least 50% of the fibers must have fiber straightness ≥ 0.75 for a lot to pass quality control. After each lot of fibers is analyzed, the filter bins instantly populate with a percentage of particles matching the passing criteria, allowing operators to quickly assess whether a particular lot has passed.

Filter Statistics

| Name | Count | Count % | P/ML |
|---|---|---|---|
| Pass - Fiber Straightness 0.75+ | 10712 | 60.12 | 40791.77 |
| Cellulose Fibers_Lot 08765 | 10712 | 60.12 | 40791.77 |
| Fail - Fiber Straightness 0.74- | 7106 | 39.88 | 27059.96 |
| Cellulose Fibers_Lot 08765 | 7106 | 39.88 | 27059.96 |

**Figure 5.** Custom value filters for cellulose fiber testing. In this example, a lot passes quality control if ≥ 50% of particles have a fiber straightness value of 0.75 or higher. This particular lot would pass with 60.12% of fibers meeting acceptance criteria.

An added benefit of VisualSpreadsheet is the ability to directly interact with the filter grid and data plots. By selecting the "Pass – Fiber Straightness 0.75+" filter, particle images that match the filter will automatically display in the View Window (Figure 6, next page). These particle images can then be sorted, selected, and/or saved. Regions of histograms or scatterplots that contain particles matching the filter will also be highlighted. Data can be easily exported into Excel or as a PDF document for a seamless reporting and archiving process.

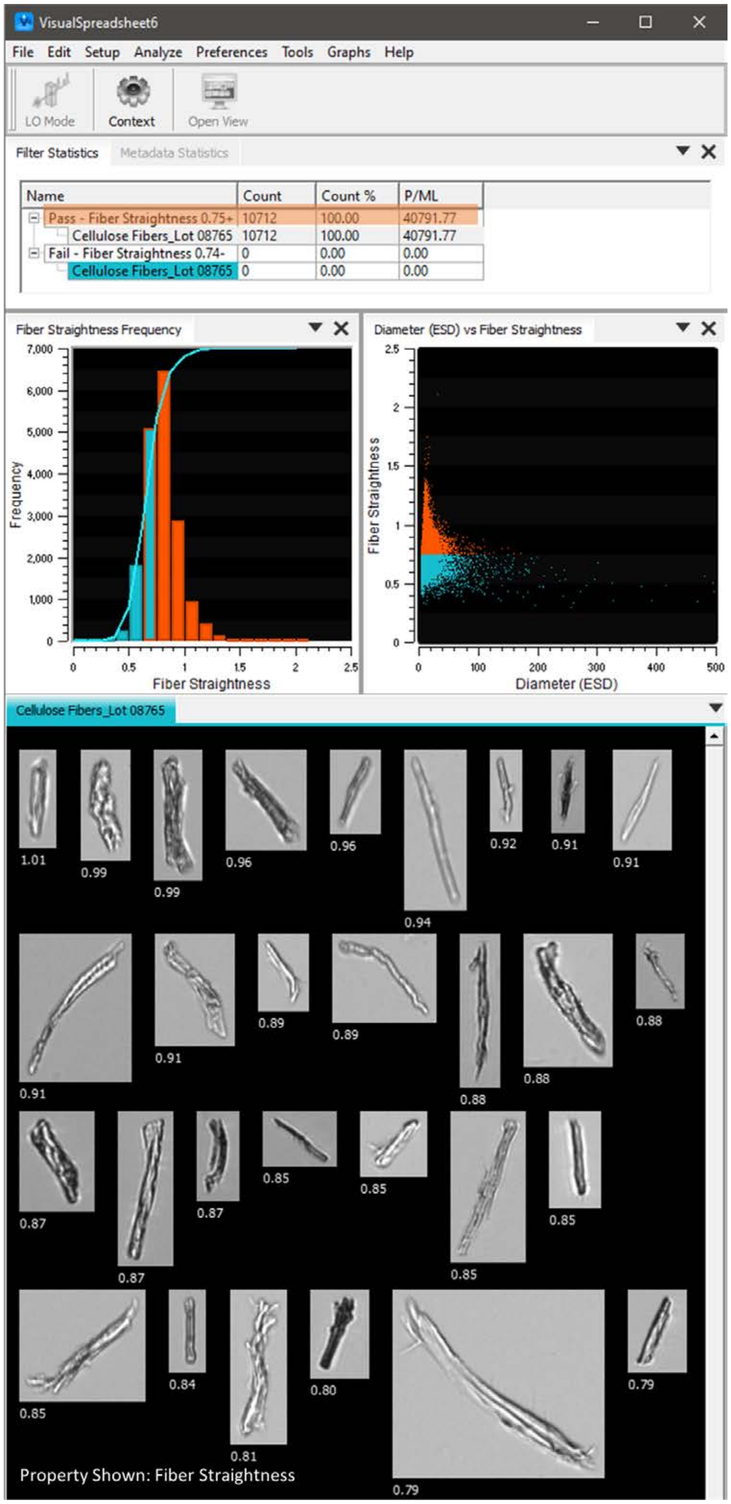



**Figure 6.** The "pass" filter (orange shading) has been selected, automatically highlighting and selecting matching particles in histograms and scatterplots. Images matching the filter automatically appear, allowing users to directly interact with particle images associated with specific filter parameters.

## CONCLUSION

FlowCam is a powerful analytical tool that expedites and streamlines fiber analysis. Integrated fiber morphology parameters include geodesic length, geodesic thickness, fiber straightness, and fiber curl. Using these measurements, FlowCam provides more accurate and reliable data than volumetric-based methods and offers a significant time-savings over manual microscopy. The option of building custom filters in VisualSpreadsheet allows for instantaneous reporting of results at the conclusion of sample analysis, saving users time and effort in assessing fiber quality.