

Preliminary Modeling of Single Pulp Fiber Using an Improved Mass–Spring Method

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Measurement of the Elastic Modulus of Single Paper Fiber

Based on the theory of beam bending under transverse load [S1], a method has been proposed to calculate the elastic modulus of paper fibers, which is briefly summarized by the following steps [S2,S3]:

Use fluorescence to dye different types of fibers separately and dilute the fibers to the concentration of 0.03%.

Drain the pulp onto a piece of filter paper and place the filter paper on two pieces of dry blotting paper.

Press the filter paper on a glass slide with some glass fibers. When hanging on the glass fiber, the paper fiber will bend under the action of a transverse load q and the support of glass fiber.

Use a confocal laser scanning microscope (CLSM) to find single paper fiber hanging perfectly on single glass fiber, which means that the single paper fiber and the glass fiber should come into contact vertically. The experimental schematic is drawn in Figure S1.

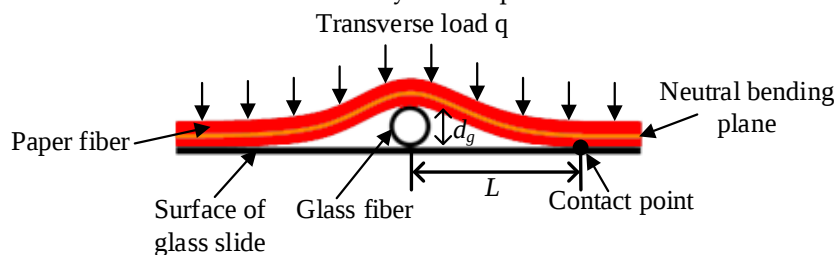


Figure S1. Experimental schematic of bending beams under transverse load for single paper fiber

Measure the free span length L of paper fiber hanging on the glass fiber and calculate the flexibility $Flex$ of paper fiber as:

$$Flex = \frac{72d_g}{qL^4} \quad (S1)$$

where d_g is the diameter of the glass fiber, and q is the transverse loads actuating on the paper fiber.

By operating in the YZ scanning mode of CLSM, the image of the cross-section of paper fiber is obtained (Figure S2).

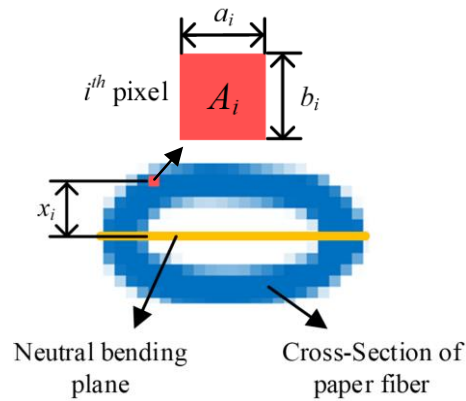


Figure S2. Illustration of single paper fiber cross-section with bending beams under transverse load

According to the definition of cross-sectional moment of inertia in material mechanics [S4] and the experimental schematic in Figure S2, the cross-sectional moment of inertia I can be calculated as:

$$I = \sum I_i = \sum \left(\frac{a_i b_i^3}{12} + A_i x_i^2 \right) \quad (S2)$$

where I_i and A_i are the moment of inertia and the area of the i^{th} pixel of paper fiber cross-section in the image, respectively; a_i and b_i are the width and height of the i^{th} pixel; x_i is the distance of the i^{th} pixel to the neutral bending plane.

Calculate the elastic modulus E of paper fiber by the definition of E as:

$$E = \frac{1}{Flex \cdot I} \quad (S3)$$

References

- S1. Qi, L.; Huang, S.; Fu, G.; Zhou, S.; Jiang, X. On the mechanics of curved flexoelectric microbeams. *Int. J. Eng. Sci.* **2018**, *124*, 1–15. <https://doi.org/10.1016/j.ijengsci.2017.11.022>.
- S2. Steadman, R.; Luner, P. The effect of wet fibre flexibility on sheet apparent density. In *papermaking raw materials*, *Trans. of the VIIIth Fund. Res. Symp, Oxford, UK, 1985*; Punton, V., Eds; MEP: London, UK, 2018; pp. 311–337.
- S3. Yan, D.; Li, K. Measurement of wet fiber flexibility by confocal laser scanning microscopy. *J. Mater. Sci.* **2007**, *43*, 2869–2878. <https://doi.org/10.1007/s10853-007-2085-9>.
- S4. Hibbeler, R. *Mechanics of materials*, 8th ed.; Pearson Prentice Hall: Hoboken, NJ, USA, 2011.