Elucidating the Nature of Fiber-Fiber Bonding via FRET and Fluorescence Microscopy

Cameron Thomson, Rob Lowe, Art Ragauskas
Institute of Paper Science and Technology
Georgia Institute of Technology

ABSTRACT

A new technique utilizing fluorescence resonance energy transfer (FRET) has been developed to characterize and quantify fiber-fiber bonded area. A model system employing sheets made from viscose staple fiber and a coumarin-fluorescene FRET dye pair demonstrate a FRET-like response which appears to correlate with sheet consolidation.

INTRODUCTION

The most fundamental and practically important property of paper is the physical/chemical parameters involved in fiber-fiber bonding. Currently, no method exists that has the capability to study fiber-fiber bonds on the appropriate scale. An application of FRET provides a new opportunity to study fiber-fiber interactions on a molecular scale.

FLUORESCENCE RESONANCE ENERGY TRANSFER

Fluorescent molecules absorb light energy at one wavelength and then emit light energy at a longer wavelength. When the emission spectra of one fluorescent molecule (the donor) sufficiently overlaps with the absorbance spectra of another fluorescent molecule (the acceptor), energy transfer can occur. The transfer is distance dependent and is characterized by an intensity decrease in the donor emission spectra and an increase in the acceptor emission spectra (see Figure 1).

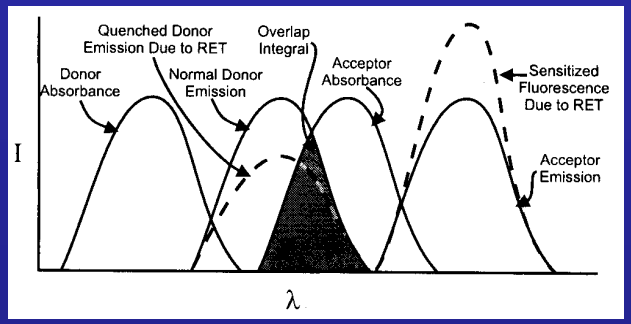

Figure 1 – Fluorescence resonance energy transfer [Herman. *Fluorescence* Microscopy, *2nd Edition.* 1998].

METHODS AND MATERIALS

- Viscose fibers (Lenzing Austria) were pre-treated with a mild periodate oxidation in order provide covalent linkage sites for the FRET dyes.
- Two dyed fiber samples were prepared using hydrazine derivatives of coumarin and fluorescein dyes to covalently bind the dye to the viscose fibers.

Figure 2 – Viscose fibers: Un-dyed (left), fluorescein dyed (center), and coumarin dyed (right).

- Each sample was then exhaustively washed with hot dimethylformamide (85☜C) to remove excess dye followed by Soxhlet extraction with methanol to remove any traces of solvent.
- Sheets were then prepared containing fluorescein dyed fiber, coumarin dyed fiber, and an equal mixture of both dyed fibers.
- The sheets were then hot wet pressed to various levels.
- Each sample was analyzed using the ISS PC-1 spectrofluorometer.

RESULTS

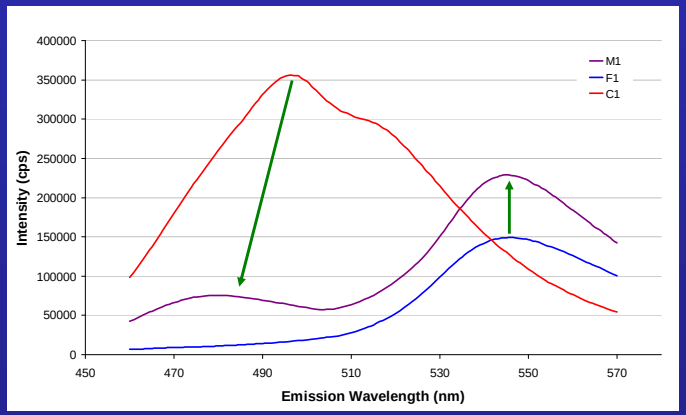

Figure 3 – Emission spectra of viscose sheets containing fluorescein dyed fibers (F1), coumarin dyed fibers (C1), and a mixture (M1).

- Figure 3 shows a typical FRET response as indicated by the green arrows.
- This result indicates that some portion of the fiber surface area is within 10 nm.

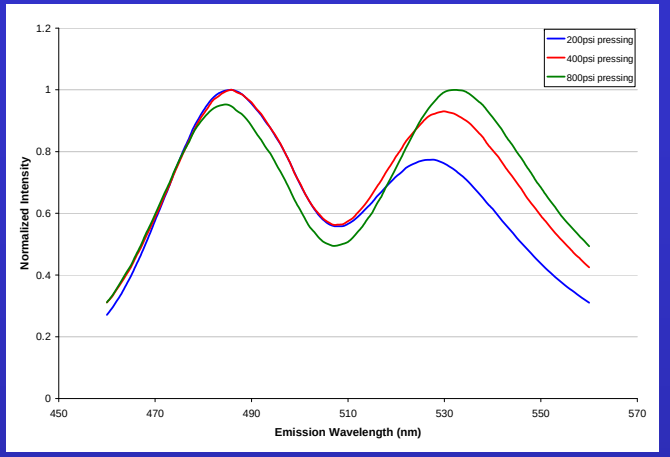

Figure 4 – Normalized emission spectra of viscose sheets wet pressed to different level containing both fluorescein dyed and coumarin dyed fibers.

- The FRET response increases as sheet consolidation increases.
- Either fiber-fiber distances are being decreased to allow higher energy transfer efficiency or new fiber areas are being brought within 10 nm.

STATUS OF DELIVERABLES

- Literature review measuring bonding area and fiber-fiber bonding fundamentals. {COMPLETE}
- A method for the controlled labeling of cellulosic materials with fluorescent dyes. {COMPLETE}
- Demonstration of FRET methodology for studying model fiber systems. {COMPLETE}
- Determination of fiber-fiber interface topography with nanometer resolution. {ONGOING}
- Fundamental understanding of how a fiber-fiber bond forms during wet pressing and drying. {ONGOING}

CONCLUSION

This work has yielded a never before seen FRET response at the macro scale. These findings demonstrate the immense potential for the study of cellulosic fiber networks using FRET spectroscopy.

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