Fiber Motion and Yarn Forming in High Speed Air Flows F99-S06

http://www2.ncsu.edu/unity/lockers/project/ntcprojects/projects/F99-S06/index.html

Principle Investigators
William OXENHAM (NCSU)
Memis ACAR (Loughborough University/NCSU)
Chongwen YU (China Textile University/NCSU)

Graduate Research Assistants
Guldemet BASAL
Nikhil DANI
YiYun CAI

Abstract

A brief overview of the areas of applications of air streams in textiles is presented along with examples of earlier research. Preliminary investigations have been initiated into two different areas of utilization of high-speed air streams in yarn production. While these are both associated with the use of an air stream to bend and twist fibers the end products are very different. The first area is air jet texturing of filament yarns where the focus has been the role of fiber wetting and fiber finish. The second area is the use of air to generate false twist in cotton spinning and the study has evolved around the structure generated in new technology of Vortex spinning. It is intended to utilize the data generated from these preliminary studies into a fundamental study of air/fiber interactions and appropriate modeling techniques and software tools are presently being researched.

Project Goal

Great use is being made of air in the processing of fibers and yarns into textile products. Examples of such uses are in fiber extrusion, spinning preparation, spinning, texturing, and weaving, plus auxiliary uses such as cleaning and cooling of machines and products. While this affords certain advantages with respect to speed of manufacture, it may also introduce economic and technical penalties. The primary goal of the project is to develop a clearer understanding of the behavior of textiles in high-speed air streams. Emphasis will be placed on establishing models that can elucidate the interaction of fibers with airflows. Initially these models will be used to study how optimum use can be made of air to separate, condense and twist fibers. The study will subsequently be extended to other areas of textile product and process development.

Background

Developments in science and technology have brought about radical changes in the textile industry. While the major focus of many reports has been the incorporation of microprocessor technology into almost all areas of textile manufacture, little has been published about another area of development, which is the significant growth in the use of high speed (or high pressure) airflow in many textile processes. While airflow technology has been used in textile processing for a long time, high-speed airflow has recently gained greater significance in textile processing. Indeed this general technology forms the basis (or is a critical component) of many “new” processes such as:

- rotor, air-jet, vortex and friction spinning;
- intermingling, air texturing, and splicing;

- melt blown and air-lay nonwovens;
- air-jet weaving;
- advanced fiber and yarn testing equipment.

While there have been studies on airflow these have been mainly on low speed flows or have tended to concentrate on specific machines. In the area of staple yarn manufacture there are five essential steps, namely: - separating, cleaning, drafting, condensing and twisting. Compressed airflow can be used to achieve all of these steps because of its high speed and energy. However recent incursions into processes such as jet spinning have clearly shown that there can be disadvantage associated with the use of air in fiber processing and in particular its different interaction with different fibers, (which has currently restricted this technology to polyester rich blends). Furthermore concerns about the economics of jet spinning, due to inefficient use of the air, has resulted in ongoing “improvements” such as the substitution of air twisters by mechanical twisters.

Even though there is reported experimental work regarding airflow in fabric and yarn processing there is a scarcity of publications on the modeling of fiber and yarn motion in airflow. Furthermore very little of the reported work relates to high speed air streams. For convenience, typical (i.e. representative) publications can be grouped as follows:

<u>Airflow/yarn interaction:</u>

In 1968, B Edberg reported the results of a basic experimental investigation into the possibility of parallelizing and stretching cotton fibers by using aerodynamic forces [B Edberg, in: Studies in Modern Yarn Production, The Textile Institute, Stresa, 1968]. The range of air velocities varied from 5 to 100 m/s. A similar study using synthetic monofilaments was reported by J Gould and FS Smith [J. Text. Inst., **71**, 38-49 (1980)].

<u>Air-jet spinning:</u>

W Oxenham et al. conducted an experimental study of the air-jet spinning process [J. Text. Inst., **78**, 189-203 (1987)] and also looked at the twist distribution and twist insertion rates in relation to the twisting kinematics [J. Text. Inst., **78**, 204-219 (1987)]. W Oxenham and A Basu studied the effect of jet design parameters, such as diameter and orifice angle, on the properties of air-jet spun yarns [Tex. Res. J., **63**, 674-678 (1993)].

<u>Rotor spinning:</u>

M Acar et al. investigated experimentally fiber alignment in opening for open end spinning [Tex. Res. J., **63**, 309-312 (1993)]. Method of producing fancy yarns in rotor spinning by utilizing jets to alter the distribution of the fiber flow was reported by J Kwasniak [J. Text. Inst. Pt. 1, **87**, 321-334 (1996), J. Text. Inst. Pt. 1, **88**, 174-184, 185-197,198-208 (1997)]. LX Kong and RA Platfoot applied a two-dimensional computational fluid dynamics model; to simulate the flow patterns inside the transportation zone of a rotor-spinning machine [Text. Res. J., **66**, 641-650 (1996)], and to simulate fiber movement within confined channels [Text. Res. J., **67**, 269-278 (1997)].

<u>Air-jet texturing:</u>

Filament yarn behavior in the airflow in air-jet texturing were experimentally analyzed by M Acar et al, [J. Text. Inst., **77**, 28-43; **77**, 235-254; (1986)]. They also developed a mathematical model of the airflow in high-speed air-jet texturing nozzles, which demonstrated a good agreement with the experimental results. M Acar et al also reported experimental work on the effect of nozzle geometry on the flow characteristics and the texturing performance of the air-jet texturing nozzles [Tex. Res. J., **64**, 240-246, (1994) and **66**, 83-90, (1996)].

Air-jet weaving:

An experimental investigation of weft yarn insertion using air jets was carried out by by MH Mohamed and M Salama [Tex. Res. J., **56**, 683-690, (1986)] and Salama et al. [Tex. Res. J., **57**, 44-54, (1987)]. This was followed up by a study of the influence of yarn structure on air jet weaving by S Adanur and MH Mohamed [J. Text. Inst., **79**, 316-329 (1988]. M Ishida et al. experimentally studied the influence of tube design on the characteristics of the airflow [J. Tex. Mach. Soc. of Japan, **37**, 8-13 (1991)]. N Iwaki et al. analyzed the yarn tension in air jet nozzles used for weft insertion and related this to airflow rate and jet velocity [J. Tex. Mach. Soc. of Japan, **37**, 35-40 (1991)]. Further studies in this area have been subsequently performed by S Adanur and MH Mohamed [Text. Res. J., **61**, 253-258 (1991)] and [J. Text. Inst., **83**, 45-55, 55-68 (1992)], and V. Natarajan et al. [J. Text. Inst., **84**, 314-325 (1993)].

Computational Fluid Dynamics:

While there is very limited published information in this area, the mathematical modeling of "industrial fiber processing technologies" has been reported by Roberts [Textile Res. J. 66(4), 195-200(1996)] and Smith & Roberts [Textile Res. J. 64(6), 335-344 (1994)]. This has been primarily concerned with "large-production fiber processing industrial facilities" and concentrated on features such as the uniformity of the final assembly.

It is believed that the current lack of general understanding of the interaction of fibers and fiber assemblies in the field of a compressed airflow is imposing limits on the process efficiency and product quality. There is no doubt that air could be potentially used to simplify many textile processes, but without a better base knowledge any wider application of air streams will be curtailed.

Preliminary Trials

The main focus of the project is the development of a fundamental understanding of the interaction of fibers with high-speed airflows and the establishment of suitable models to optimize the use of air in fiber manipulation. It was however considered worthwhile to develop background experimental knowledge in two areas of yarn formation namely air texturing and vortex spinning. This work was carried out by two of the graduate students prior to the appointment of the final team member who will focus on the development of suitable models. The areas selected for experimentation were considered appropriate since they are representative of current processing technologies and span the range of fiber types.

The first area - air texturing - will probably form the basis of the first model since the air stream is used primarily to bend the filaments, which constitute the yarn. There are however features that are known to influence the efficiency of the texturing process and these are the nature of any fiber finish and the presence of water on the yarn prior to passing into the air stream. The exact role of these agents on the interaction of filament on filament and air on filament, is not well understood. It is believed that the data generated from the trials, when used in conjunction with the future models, could provide a better insight into this process and result in improvements in the quality of the process and the product.

The second area - vortex spinning – is being hailed as the future technology for short staple spinning. In this process the use of air is also critical but much more complex than in texturing. Air is used not only to transport and maintain the integrity of the fiber assembly, but is also used to impart false twist into the structure and to generate a two-part structure consisting of a core of parallel fibers wrapped with an outer sheath. The optimum use of air will be critical if this process is to succeed since this will govern the acceptance of the process when judged not only in terms of yarns structure (and hence yarn and fabric properties) but also in terms of utilization of air, which will determine the economics of processing.

Air Texturing

Air jet texturing is widely known for its ability to introduce spun-like characteristics into continuous filament yarns This is achieved by utilizing high speed air streams to deflect the filaments and introduce interlocking loops in the yarn structure. Along with compressed air, the other very critical component of this technology is water. Water plays a very important role in altering the behavior of fibers in air and the mechanism for this behavior is still not fully understood. It is thought that the water either interacts (removes?) the fiber finish or that the water acts to effectively increase the fiber diameter. The following experimental work was carried out to throw more light on this matter and to generate some data on the role of fiber properties and fiber finish on the effectiveness of air-fiber interactions.

- *Experimental Specifications*:

Nylon and polyester yarns of different linear densities were textured using TASLAN nozzle on an EMAD air-texturing machine at 300 m/min. An overfeed of 20%, air pressure of 2 kg/cm^2 and mechanical stretch of 6% were used, during both dry and wet texturing. Yarn were wet textured using $1 kg/cm^2$ pressure and 1 liter/hour/jet water consumption rate. Figure 1 shows the experimental set up used.

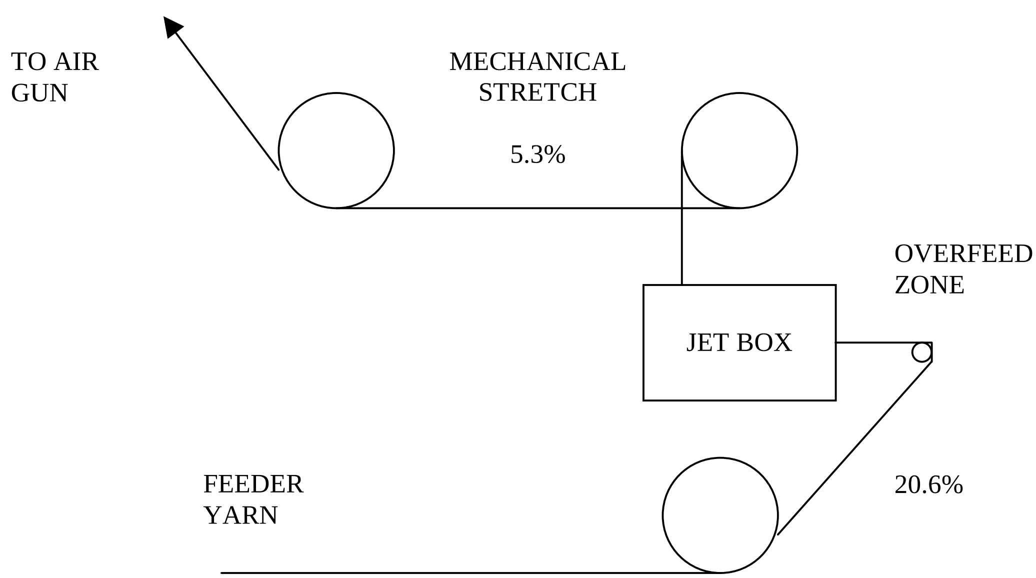

Figure 1. Experimental setup at NCSU, College of Textiles

Diameter measurements:

The individual filament diameter measurements were made using Optical Microscope. The purpose of this experiment was to determine whether the presence of water influenced fiber size. The results shown in Figure 2 clearly show that water has very little effect on fiber diameter.

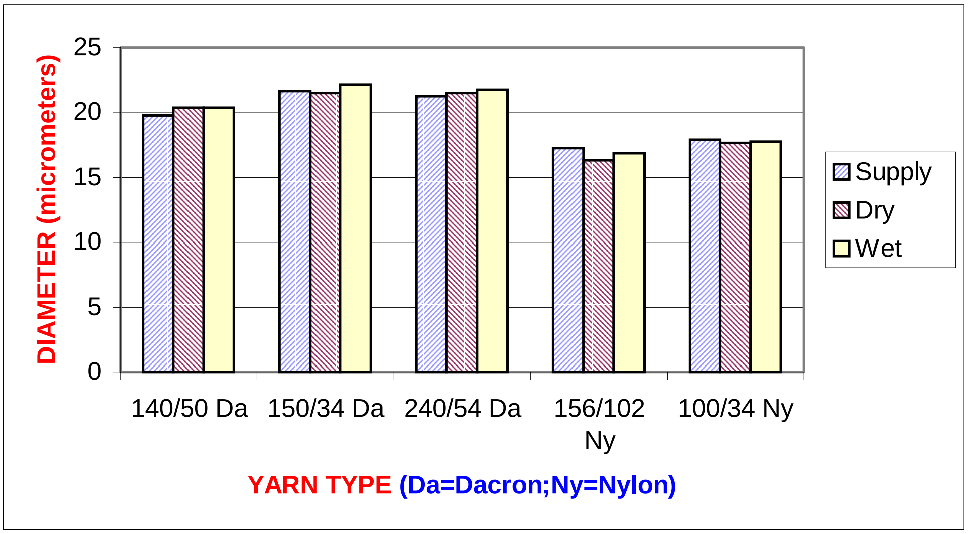

Figure 2. Filament diameter Measurements

Friction tests:

These tests were performed on the Lawson Hemphill CTT. The purpose was to show whether the frictional properties of filaments change in presence of water and air. Figure 3 shows the data for yarn to metal friction.

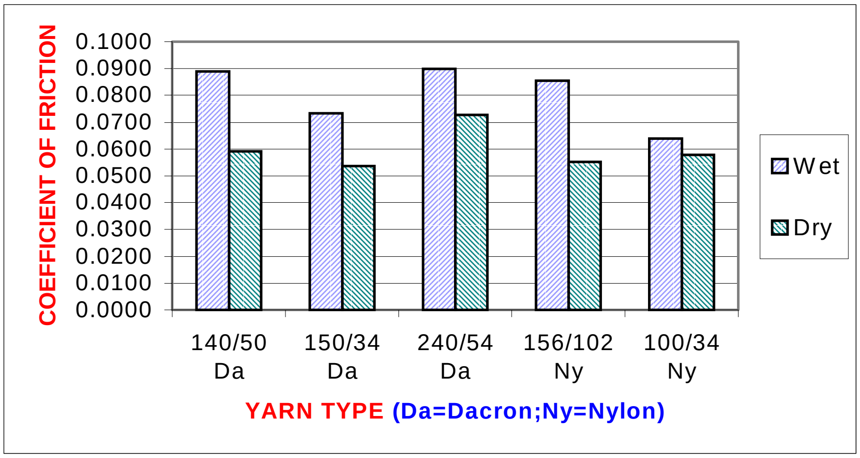

Figure 3 Yarn to Metal Friction

Figure 4 illustrates changes in yarn to yarn friction. It is apparent that the presence of water seems to have little effect on yarn to yarn friction but has a major influence on yarn to metal friction.

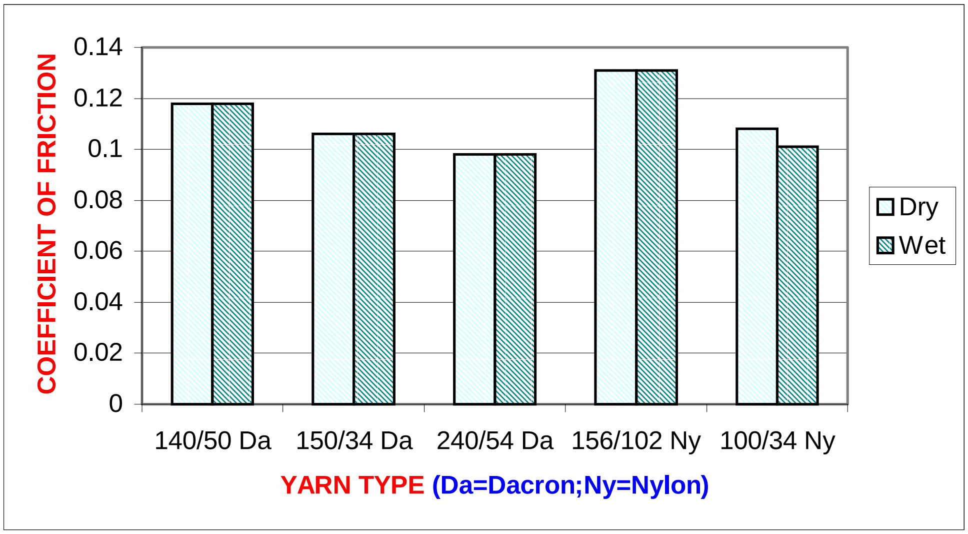

Figure 4 Yarn to Yarn Friction

Spin finish tests:

These tests were performed using the Soxhlett apparatus in order to study the effect of water on the removal of resident spin finish on the yarn and how this affected the behavior of the filaments in airflow. Figure 5 shows the measure values of the supply yarn and the yarn after texturing with and without water.

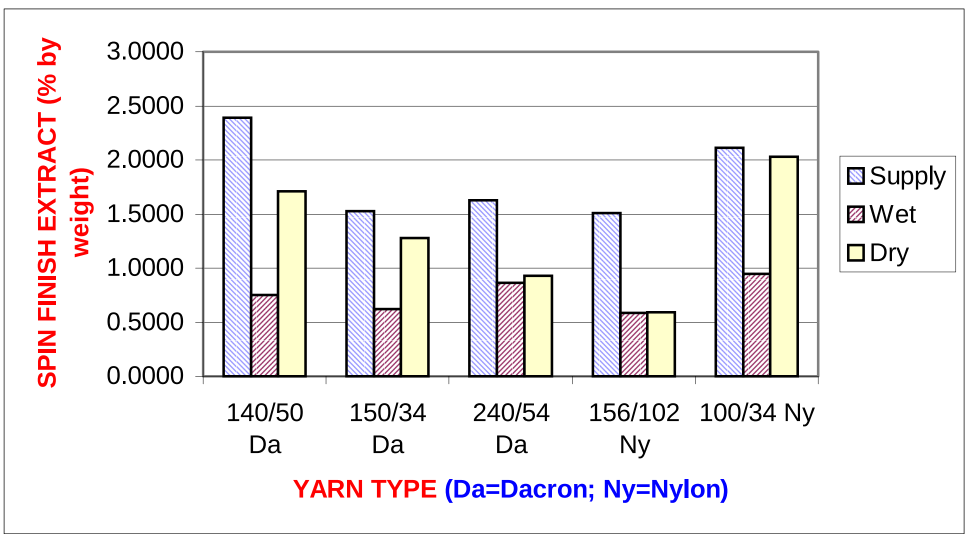

Figure 5. Spin finish measurements

Tenacity Tests:

In order to assess possible locking of the yarn structure, and any fiber damage caused by the interaction with the texturing jet, tensile strength tests were conducted on individual filaments as well as Yarns (both dry and wet textured). The data is presented in Figure 6, from which it can be seen that the presence of water results in a greater reduction in yarn strength.

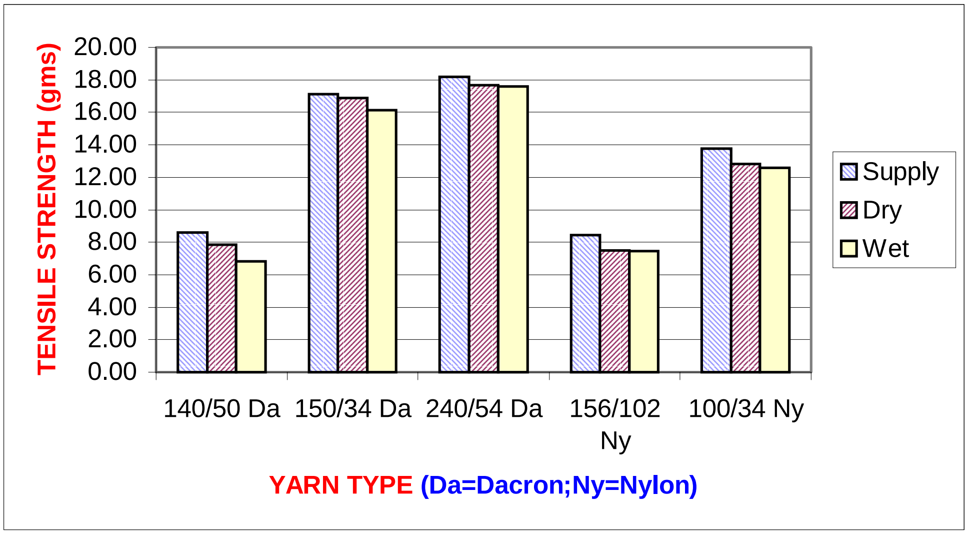

Figure 6. Individual filament strength test

Vortex Spinning

Air has been used as a twisting medium for high speed processing of staple fibers and a commercial application of this technology is Jet Spinning, which has been reasonably successful in the processing of polyester rich blends. Unfortunately Jet Spinning has several limitations that have restricted its use, both in terms of the fibers that can be successfully processed and the areas where the yarns can be used. The major limitations relate to the fact that 100% cotton cannot be successfully processed and the system will not produce acceptable coarse count yarns. Explanations for these limitations and possible solutions have been reported [Oxenham W. - "Vortex Spinning - A Natural Evolution", Presentation to EFS System Conference, May 1999, Greenville SC] and these are associated with the fiber feed and ultimate yarn structure.

Vortex spinning was recently officially launched as a “new” technology for spinning short staple fibers but as with Jet Spinning its success will depend on the optimum use of air to create appropriate yarn structure and properties. A major difficulty with Jet and Vortex spinning is that, because of the machinery design and very high speeds involved, it is impossible to actually "see" how the yarn is formed. The yarn formation mechanism is thus deduced from an analysis of the structure of the formed yarn. Initial studies on Vortex yarn clearly indicate that its structure (Figure 8) seems to be much more regular than Jet spun yarn (Figure 7) and there is evidence of a distinct sheath core structure.

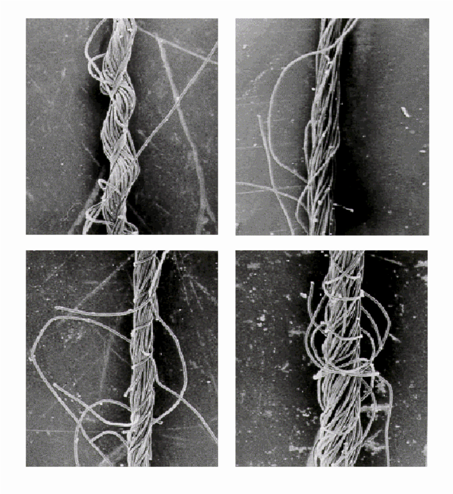

Figure 7. Jet spun yarn structure

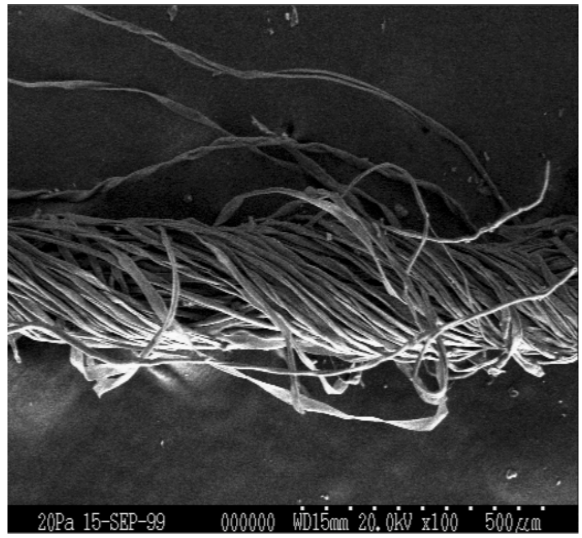

Figure 8. Vortex yarn structure

This two part structure is much more apparent if the Vortex yarn is "untwisted" when the core- sheath components look like two yarns (Figure 9).

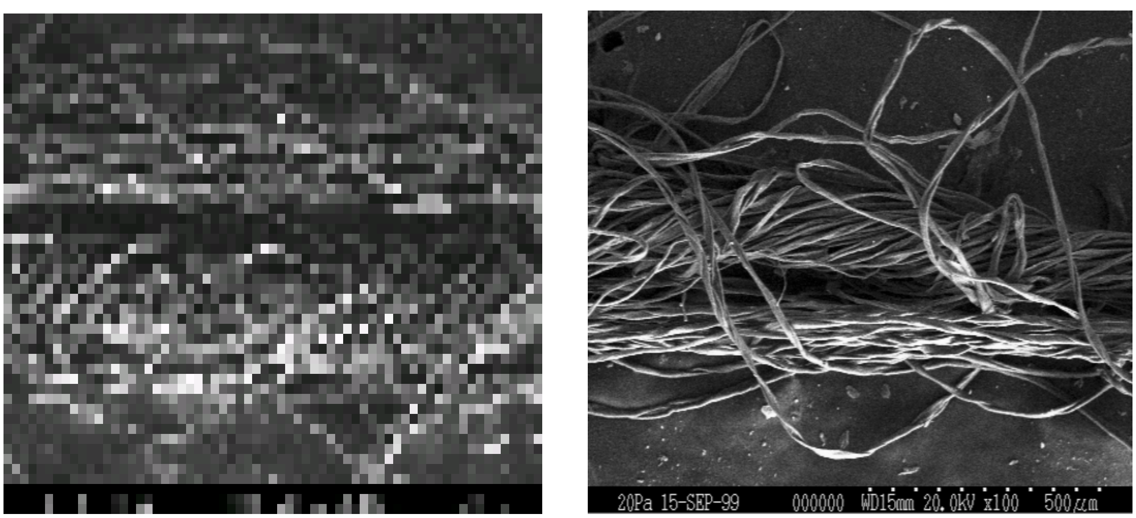

Figure 9. “Untwisted” vortex yarn showing distinct sheath core structure

<u>Ongoing Work</u>

Work in the above experimental areas relating to both staple and filament yarn formation will continue but will focus on the issue of fiber/air interactions in these systems. The data generated will be used either as an input into the models or used to verify any predictions from the models. It is also intended to carry out some "off line" testing of the magnitude of the effects of air streams on different fibers. This will include the role of air speed and pressure and how they apply tension and torque to individual and grouped fibers. Background information is being collated, which will be used in the modeling of the movement and deformation of fibers in air streams. Work will shortly begin on the models and effort is currently focussed on establishing the appropriate assumptions for the model.