BENEATH THE GRIME: MEASURING THE EFFECTS OF PRESERVATION TREATMENTS FOR TEXTILES

FENELLA G. FRANCE

ABSTRACT—Traditionally, assessments of the relative success of a textile cleaning treatment have been based on empirical observations about changes in the textile's degree of surface soiling and handling characteristics. Visual information regarding fading also has been used to assess the impact of a treatment or the consequences of display, but visual information alone does not give an accurate measure of the changes in material structure, as it only focuses on the chemical changes within the dye structure and not on the fiber itself. While important, these characteristics provide limited information on other important changes in the mechanical or chemical properties of the textile. Measurements of changes in specific mechanical properties of fibers provide a quantitative measure of changes in the physical structure of the textile. These physical changes, direct manifestations of chemical deterioration in the fiber structure, provide invaluable information regarding the impact of a particular treatment. Fiber stress and strain, evaluated by the measurement of extensibility and load at break, have been used for this purpose. This testing method also provides critical information about the current state of the textile. This is critical information for making decisions about handling procedures, display requirements, and future treatment.

TITULO—DEBAJO DE LA SUCIEDAD: EVALUANDO LOS EFECTOS DE LOS TRATAMIENTOS DE PRESERVACIÓN PARA TEXTILES. RESUMEN—Tradicionalmente, los métodos para evaluar un tratamiento de limpieza de relativo éxito se basan en observaciones acerca del cambio en el grado de suciedad de la superficie y las características de manipulación de un textil. Estos criterios son importantes, pero proveen una limitada información sobre los cambios en las propiedades mecánicas o químicas del textil. También se ha usado información visual respecto de los tintes para evaluar el impacto de un tratamiento o las consecuencias de un periodo en exhibición, aunque esto no da una medida precisa de los cambios en la estructura del material, ya que solo pone atención en los cambios químicos dentro de la estructura de los tintes. La medición física de los cambios en las propiedades mecánicas específicas de las fibras, proveen una medida cuantitativa de los cambios en la estructura física del textil. Estos cambios físicos, que son manifestaciones del deterioro químico en la estructura de la fibra, entregan invaluable información considerando el impacto de un tratamiento en particular. Con este propósito, se ha evaluado el estrés y fatiga de la fibra a través de la medición de la extensibilidad y la resistencia a la ruptura. Este método de prueba también provee información crítica acerca del estado actual de deterioro del textil; lo que es de ayuda en la toma de decisiones acerca de los procedimientos de manipulación que se usan, los requerimientos de montaje y futuros tratamientos de conservación.

1. INTRODUCTION

The most important characteristics of a textile fiber are its mechanical properties. When a fiber is structured into yarns or fabrics, the properties of the fiber are dependent upon the relationship between the structural arrangement of the composite and the properties of individual fibers. Understanding the properties of yarns and fabrics necessitates knowledge of these fiber properties.

BENEATH THE GRIME: MEASURING THE EFFECTS OF PRESERVATION TREATMENTS FOR TEXTILES

Yarns and fabrics are limited by the component fiber properties, because although fiber variability provides reinforcement within the structure, yarn strength will not exceed the total maximum strength of the fibers from which the yarn is assembled. Mechanical characteristics define the overall changes by determining what has taken place during the life of a historic textile and measuring the effects of these changes. One category, tensile properties, provides a valuable mechanical assessment of handling characteristics.

The textile's condition is dependent upon the object's history. This history includes the manufacturing processes it has undergone, any mechanical damage due both to use as a textile and from subsequent treatment, and the conditions to which it has been exposed, including agents of deterioration (light, fluctuating relative humidity, pollutants, extreme temperatures, and general soiling). For museum textiles, display and storage conditions need also to be addressed. All of these factors require consideration within the gamut of events that comprise the entire aging process.

2. TENSILE PROPERTIES

Because of the fiber's linear dimensions, its most important mechanical properties are tensile ones, as these tensile properties reflect any changes due to forces or deformations applied along the fiber axis. Tensile attributes that can be measured are fiber elongation and load at break. These two dynamics form the basis of the stress-strain diagram, in which the area under the curve measures the energy of rupture, an overall indicator of change due to various influences upon the textile as well as a recommended measure of fragility.

2.1 THE STRESS-STRAIN CURVE

The behavior of a textile depends upon the nature and arrangement of the molecules from which it is composed, and these arrangements will vary between fibers in a given sample. The coefficient of variation of individual fiber properties should be considered, as in some instances the range of the results may be just as important as the average value of the sample fibers' properties. Because the dimensions of the fiber being tested will directly affect the results, it is imperative that tensile testing results be normalized to take into account differences in cross sectional area.

Testing of single fibers can be undertaken on a WIRA Instrumentation single fiber strength machine. Because of the fragility of aged fibers, the author developed a specific mounting technique to ensure that fiber ends at the point of contact in the electromagnetic clamping mechanism were not crushed. This enabled testing of samples that previously had been crushed in tensile testing machines such as those manufactured by Instron.

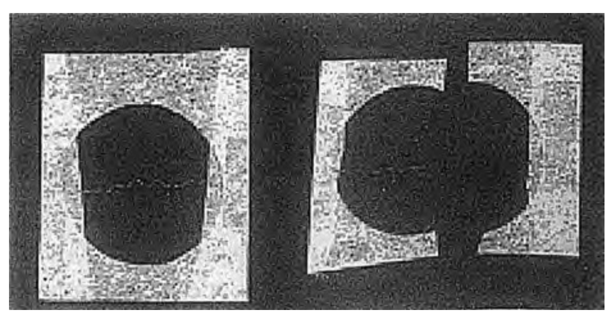

Figure 1. Fiber mounting technique.

The author's technique involved a tissue paper support cut at either side of the aperture after the fiber was held within the clamps (fig. 1).

The stress-strain curve, or load-elongation diagram, in figure 2 shows the characteristic curve for new wool fibers. Because of wool's inherent tendency to extend and absorb large deformations before breaking, there is a large yield region. The mid-section of line A indicates this region. This steady slope continues up to the limit of extension of the internal structure of the keratin protein, which occurs at about 32-35% extension. Extension beyond the yield region is resisted by covalent bonds within the internal structure. When the internal stress has increased to the limits sustainable by the fiber structure, an internal flaw is created. Crack propagation initiates from the flaw and the fiber breaks. The characteristics of the internal flaw can include macroscopic and micro-

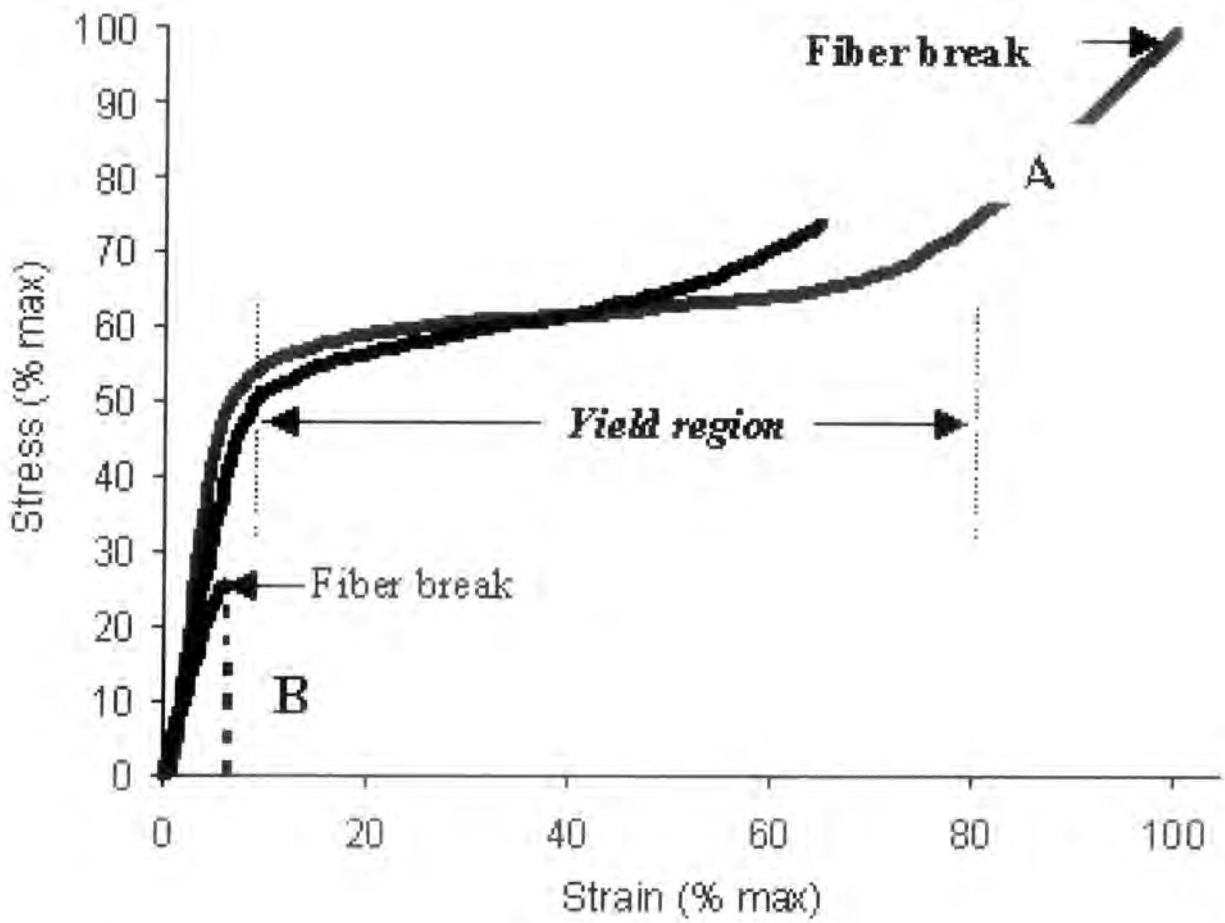

Figure 2. Stress-strain curve for wool fibers.

scopic weaknesses, as well as structural changes at the molecular level.

As fibers undergo degradation resulting from mechanical stress and from chemical deterioration of the internal structure, extensibility of the fibers decreases, and the triangular shape indicated by line B in figure 2 becomes the characteristic stress-strain curve. This curve is indicative of aged wool fibers, which show a smooth fiber fracture morphology. It is evident that while the load at break has been reduced, the decrease in elongation has a more profound effect.

Research has shown that a wide variety of treatments on new wool have an effect similar to that of degradation from mechanical stress or chemical deterioration (France 2000-2003). These treatments range from fireproofing to aqueous and non-aqueous cleaning treatments to relative humidity (RH) cycling. Also, it is evident from the time-deterioration continuum that the rate of degradation slows as the textile ages. This raises the idea that conservation is imperative in the early stages of a textile's lifetime to slow the initially rapid decrease in mechanical properties. Because most textiles have undergone varying degrees of use, a textile has already deteriorated by the time it arrives at the museum. Being able to determine this level of degradation through simple tensile testing provides the conservator with the knowledge to determine appropriate handling and treatment options.

Single-fiber analyses greatly reduce the amount of sampling required from a textile, thereby minimizing impact on the artifact. Because a combination of factors lead to yarn failure, defining the stress-strain properties of the single-fiber unit from which these yarns are made provides a more comprehensive representation than a gross evaluation of the yarn. A statistically significant sample can usually be obtained from a 5 cm (2") yarn – this ability is to a large extent based upon skillful extraction of fragile fibers and the tightness of the yarn twist. Research has shown samples to be comparatively similar even in large artifacts. One approach to ensure that the full range of fiber strength is measured is to sample from both a damaged area and an intact area of the textile.

2.2 ENVIRONMENTAL INFLUENCES

While the energy of rupture provides a measure of deterioration, the changes in fiber strain or elongation serve as advance warning of problems, as the effects of display and storage profoundly affect fiber elongation (France 2000-2003). Textiles are extremely susceptible to light and to relative humidity changes. While chemical analyses of the effects of severe light damage can indicate changes in light-degraded amino acids such as cystine, these analyses do not necessarily give a direct measure of the changes or effect of this damage upon the mechanical properties of the textile, such as increased brittleness; therefore, relevant and often critical information relating to handling and display parameters for the textile is not available if tensile testing does not form part of the analysis. Such physical manifestations of chemical changes in the internal textile fiber structure are a practical indicator of both chemical and mechanical changes, thus enabling a more direct assessment of reduced stability and decreases in mechanical properties.

Changes in RH are important in relation to fiber mechanical properties, as RH fluctuations cause small changes in fiber dimensions. If repeated over many cycles, these changes can slowly generate microscopic flaws in the textile fibers; these flaws are of greater concern as the artifact ages and becomes more fragile. Evidence that micro-flaws may propagate planes of weakness for fiber fracturing supports the recommendation for maintaining a constant RH. Modern fracture mechanics has established that macroscopic breaks are initiated by microscopic flaws. Gamez-Garcia (1999) observed the effects of repeating small surface mechanical deformations in keratin fibers using surface strains of about 0.2%. When repeated over a number of cycles, these strains created micro-voids and axial cracking. Experiments with cycling RH regain changes of 10% showed a marked effect on the extensibility of photo-aged wool (France and Weatherall 1998-1999). Erhardt et al. (1995) have recognized that damage to cottonwood materials may be related to repeated small tangential deformations caused by changes in RH. With some fibers, frictional forces increase as the regain of the fibers is raised; it is evident that RH has consequential effects on mechanical properties with the potential to increase or decrease forces on the textile in terms of its display orientation. In the past it has been suggested that much of the research carried out does not directly answer the questions that arise in a museum context (Feller 2002). Controlling environmental variables in the museum environment is critical. It is necessary to address the issue of changes in historic artifacts and how these items are detrimentally affected by environmental influences.

2.3 FIBER FRACTURE

Museum textiles are subjected to a diverse range of influences. Most textile research relates to determining changes in properties while textiles are in use, as opposed to changes due to museum conditions and treatments, although the latter type of information is critical to conservators. Some textiles may have been subjected to little more than mechanical action during their history, while others may demonstrate the results of many influences, including light, heat, and moisture. Studying the fracture morphology of individual fibers by scanning electron microscopy (SEM) can illustrate the effect of past influences. Under a high magnification microscope, the trained eye can also observe fracturing, which shows changes from normal, more fibrillar fracture surfaces (where the internal structure of the fiber can resist breakage) to increasingly smooth fractures as the fiber deteriorates (revealing a weaker interior structure) (fig. 3). Because of the characteristic brittleness of aged fibers, any deformation (i.e. tensile force, bending, shear, and twist) of the fiber is more likely to cause it to break as a result of the low energy of rupture. Fiber fracture is a direct visual manifestation of tensile properties and physical changes. While providing information about the history of the textile, it can also help determine a suitable preservation strategy. Using SEM, Massa et al. (1980) measured both fiber strength and fracture morphology for Egyptian mummy keratin fibers dated between 1500-4000 years old. The mummy fibers had similar tensile properties and the distinctive fracture

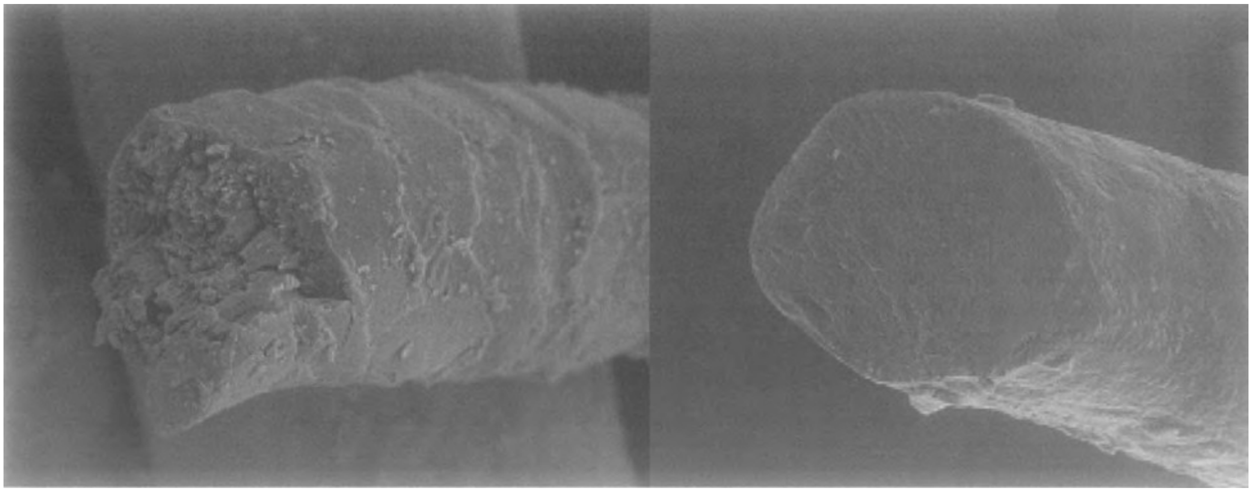

Figure 3. SEM micrograph of fibrillar (left) and smooth (right) fiber fractures (1000x magnification).

morphology comparable to old textile fibers of more recent origin. Studies such as this provide invaluable information about the effects of environmental conditions, as well as where fibers lie on the age-time degradation curve.

3. MONITORING COLOR CHANGES

Dyed textiles fade and change color upon exposure to light. A common method used to assess a textile's changes due to light exposure is the use of British Blue Wool Standards. These standards are comprised of eight samples of wool graded from 1 (very low light fastness) to 8 (very high light fastness). These standards originally were developed to monitor the effects of daylight, as opposed to the usual ultraviolet (UV) filtered light in museums.

Horie (1990) notes that both visible and UV radiation fade Blue Wool Standards with poor light fastness, while the higher number standards, which are more resistant, are affected only by the shorter wavelength components of the radiation. He found that standards 6 and 7 were unreliable when UV was excluded. Because most museum lighting is UV filtered, these standards do not provide an accurate measure of real damage. Feller (2002) observed that various dyes behave differently with respect to RH, spectral distribution of the light, and temperature. As the rate of fading does not adhere to a strictly linear relationship, the ideal relationship whereby each standard should fade at half the rate of the preceding one does not hold true. Ford (1992) showed that not only the identity, but also the history, of the dye is important, as even textiles dyed with the same dye may show different rates of fading. In addition, the spectral output of the light source, pollutants, and the extent to which a dye has already faded are critical factors.

Fading is not necessarily indicative of a change in the actual textile fiber. While there may be slower initial textile substrate deterioration compared to dye fading, this may be reversed later in the life of the textile. If assumptions regarding deterioration are based solely on fading, once the rate of fading is reduced the degradation may appear minimal, whereas internal structural changes may be occurring at a greater rate than fading. Research has shown that a photo-protective effect from specific dyes appears in some aged textiles when compared with un-dyed fabric in the same textile (France 2000-2003). Measurement of color changes, whether by blue wool standards or color measurement instrumentation, may not accurately reflect changes within the textile.

4. CONCLUSIONS

The basis of textile conservation is the extension of a textile's life. Often this involves decisions regarding cleaning or treating the textile, with the critical factor being how to obtain required information. Current accepted textile treatments are not necessarily based upon quantitative studies and a real understanding of what is happening at the structural level of the textile fiber. Increased fragility from aging may be minimized with a better understanding of the effects of treatment on the fiber's mechanical properties. This understanding will influence handling of the textile, as well as determine environmental parameters. Tensile testing can be utilized as a monitoring tool: small loose fragments of yarn can be kept with the textile and tested after a period of time to determine whether changes are within normal expected limits of age deterioration. Linking the micro to the macro (that is, connecting the fiber structural changes to the fabric handling and exhibition requirements) can provide quantitative measures of what were previously subjective observations. This allows more confidence in making future conservation treatment decisions.

ACKNOWLEDGMENTS

My sincere thanks go to Suzanne Thomassen-Krauss for the opportunity to be a researcher on the Star-Spangled Banner Preservation Project. This has enabled me to pursue and further my research interests in the area of textile degradation, and to do so in support of the project at a key time in the nation's history.

REFERENCES

Erhardt, D., M.F. Mecklenburg, C.S. Tumosa, and M. McCormick-Goodhart. 1995. The determination of allowable RH Fluctuations. *WAAC Newsletter* 17(1): 19-23.

Feller, R.L. 2002. *Contributions to conservation science: A collection of Robert Feller's published studies on artists' paints, paper, and varnishes.* ed. P.M. Whitmore. Pittsburgh: Carnegie Mellon University Press.

Ford, B.L. 1992. Monitoring color change in textiles on display. *Studies in Conservation* (37): 1-11.

France, F.G. 2000-2003. Star-Spangled Banner Internal Reports. Smithsonian Institution, Washington, DC.

France, F.G., and I.L. Weatherall. 1995. The effect of light on wool. In *Proceedings of 9th Int. Wool Textile Research Conference,* Biella, Italy. United Kingdom: The Textile Institute. II: 100-108.

France, F.G., and I.L.Weatherall. 1998-1999. Star-Spangled Banner Internal Reports. Smithsonian Institution, Washington, DC.

Gamez-Garcia, M. 1999. Plastic yielding and fracture of human hair cuticles by cyclic torsion stresses. *Journal of Cosmetic Science* 50 (March/April): 69-77.

Horie, C.V. 1990. Fading of feathers by light. In *ICOM Committee for Conservation preprints,* ed. K. Grimstad. 9th Triennial Meeting Dresden, German Democratic Republic: Los Angeles, International Council of Museums. II: 431-436.

Massa, E.R., M. Masali, and A.M.C. Fuhrman. 1980. Early Egyptian mummy hairs: tensile strength tests, optical and scanning electron microscope observation: a paleo-biological research. *Journal Human Evolution* 9: 133-137.

FURTHER READING

Hearle, J.W.S., B. Lomas, and W.D. Cooke. 1998. *Atlas of fiber fracture and damage to textiles.* 2nd ed. Cambridge, United Kingdom: Woodhead Publishing Ltd.

Morton, W.E., and J.W.S. Hearle. 1975. *Physical properties of textile fibres.* London: Heinemann, The Textile Institute.

FENELLA G. FRANCE received her PhD degree in Textile Science from Otago University, Dunedin, New Zealand, in 1995 and an MBA from Deakin University, Melbourne, Australia, in 1999. After lecturing at Otago University she was a textile and environmental scientist on the Star-Spangled Banner Project for the National Museum of American History, Smithsonian Institution. At present she is the research scientist at Art Preservation Services, New York, involved in textile and environmental related research, including special projects such as the preservation of World Trade Center artifacts for the Port Authority of New York and New Jersey. Address: Art Preservation Services, 315 East 89th Street, New York, NY 10128.
E-mail: ff@apsnyc.net