Fabric selection and its relationship to dimensional changes in support systems for constrained fabric mounting devices

Stephen Collins, Marion Mecklenburg and Mary Ballard

There has been, and still remains debate as to how to choose fabric substrates for constrained mounting devices. Selection of mounting fabrics in textile conservation is somewhat random, being dependent upon what is commercially available. Because textile conservators represent a limited market they carry very little weight in determining the types of fabrics being manufactured.

In textile conservation, constrained mounts are considered a treatment rather than simply a method of display. Traditionally, a constrained mounting fabric is stretched tautly around a wooden or cardboard strainer and held in place with staples, glue, or by being laced or sewn to itself. In concept, these mounts attempt to maintain a constant pressure, or yarn stress, which allows little room for dimensional changes. A support system must provide adequate strength and stiffness, and must be dimensionally stable so that its own physical nature will not cause distortion in the textile being supported. This concept of dimensional stability is generally considered debatable when considering the effects of changing conditions due to relative humidity.

The literature reviewed indicates that a support system must be strong enough to carry the weight of the artifact. A support system must provide adequate strength and stiffness, and must be dimensionally stable so that its own physical nature will not cause distortion in the textile being supported. When considering the long term effects of ageing, the inherent ability of certain synthetics to resist the various agents of destruction that cause degradation in natural fibre fabrics is of interest.

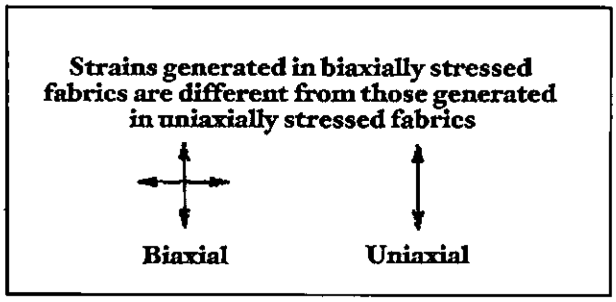

Fig. 1

There is no body of literature concerned with the scientific basis for the use of constrained mounting devices within the textile conservation literature. There is, however, a great deal of information that can be taken directly from the textile industry and from paintings conservation. Much of this literature concerns the uniaxial testing of textile fibres and yarns. Although there are some full-fabric tests, the majority of testing is done at the fibre or yarn level or with strip tests. There is a great deal of interest in the biaxial study of fabrics as fabrics are rarely stressed in a uniaxial direction. It is generally accepted that the strains generated in a biaxially stressed fabric are considerably different from those generated within a uniaxially stressed fabric (Fig.1). Brenner and Chen stated that the forces developed when a fabric is deformed are strongly influenced by fabric geometry and the magnitude of internal stresses. The ability of a fabric to recover from that deformation depends upon how that energy has been stored or dissipated.[1] Klein stated that the biaxial extension is much smaller than that of the uniaxial extension.[2]

Between 1937 and 1947, Peirce[3,4] formalised the subject of fabric geometry through mathematical analysis. In 1967, Freeston, Platt and Schoppee, considering the parameters set up by Peirce to be insufficient, identified additional deformation factors occurring in biaxially stressed fabrics.[5]

The studies of Mecklenburg[6] and Hedley[7] on substrates used for canvas paintings provide additional insights. It is Mecklenburg's thesis that assemblies of layered materials, such as paintings, can be researched by mathematically summarising the behavior of the individual materials found at each layer. If the forces developed by the separate layers of materials are added together at each point of relative humidity, a composite results. In other words, one can observe that the stress in the various layers of materials changes with relative humidity even when there is no change in strain. Mecklenburg tells us that two materials with identical dimensional responses to

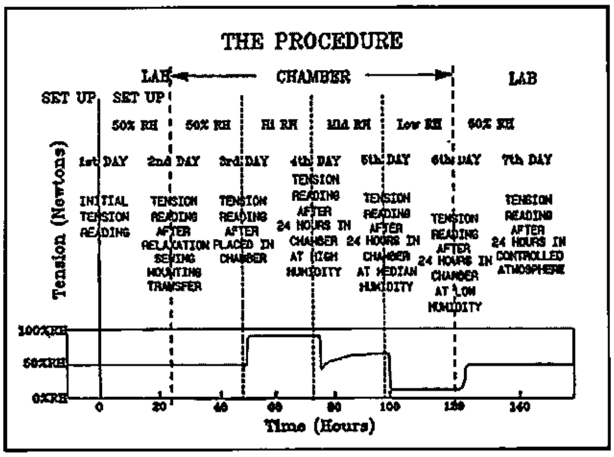

Fig. 2

moisture, upon restraint, can develop very different mechanical properties due to the modulus of one material being greater than the modulus of another.

Work at CAL by Erhardt and Mecklenburg has shown that relative humidity cycles do result in irreversible changes in some materials. Berger and Russell state that with every temperature or humidity change, some dimensional changes remain non-recoverable and that repeated variations lead to non-recoverable changes in most materials.[8] Generally slow and moderate changes are recoverable while rapid environmental changes cause disproportionately large stress variations.[9]

At low strain much of the mechanical behavior is simply the result of straightening crimped yarns.[10] After fabric crimp removal has been surpassed by continuous strain, the actual yarn behavior takes over. Upon being stretched beyond the fabric crimp removal zone, a constrained fabric when subjected to high humidity continues to relax by allowing the yarn fibres to slip past one another. Because of this, maintaining fabric tension, even in linen fabrics, with a high strain on a fabric subjected to high humidities appears impossible.

The focus of our research was to determine the fabric least affected by tension loss due to moisture while under constraint. The severity of these losses aids in determining the most appropriate fabric for use in a constrained mounting device.

The first objective was to compare the dimensional stability of a select group of fabrics, stretched on constrained mounting devices, by observing how tension is affected by the presence of moisture.

The second objective was to compare the dimensional stability by observing how tension was affected by stitching of these same constrained substrate fabrics when subjected to the presence of moisture. It is not within the scope of this study to examine and compare how stitching techniques alone affect the dimensional stability of the substrates. However, the subject of how various stitching techniques affect constrained substrate fabrics is an area for further examination.

The third objective was to compare the dimensional stability of these constrained substrates by observing how tension was affected by stitching and the presence of a mounted object, bound together in an assembly, when subjected to the presence of moisture.

The fourth objective was to observe and compare variations in tension due to the design of the strainer. For this study, two M-3 Roller Frames and two M-1X Roller Frames, all with an outside measurement of 63.5 x 86.4cm were observed. This outside measurement leaves an effective inner measurement of approximately 53.4 x 76.8cm. Other strainers to be observed were a standard wooden strainer with an outer measurement of 50.8 x 76.2cm. The fabric substrate for this strainer was stretched and brought up to tension on one of the M-3 Roller Frames. The substrate fabric was then transferred, in tension, to the strainer and attached with non-corrosive Monel staples.

The final objective was to test for unstable chemical properties within the chemical makeup of the support fabrics. Certain aspects of these mounting fabrics and of their fibre properties negate the effects of particular agents of deterioration. The Oddy test[11] was used to assess this objective, and as expected the wool outgassed and the remainder of the fabrics tested negatively.

The selection of samples

Fabrics from TestFabrics Incorporated were used to represent the combined categories of medium-weight and light-weight fabrics. The selection of sample fabrics from TestFabrics was decided upon because of this company's high visibility and history within the textile conservation profession in the United States. To reduce the influence of subject variables it was important to select fabrics from each group that are as structurally alike as possible. Only plain weave fabrics were tested. The construction, the number of ends and picks, and the overall thickness of these test fabrics were chosen to be as similar a possible.

The fabrics used to represent the light-weight category include: #435, Combed Cotton Batiste; #609, Habutae, 8mm, silk; #7435, Polyester/Cotton 65/35 Shirting; and #733,45 inch, Polyester Batiste, Filament Warp/Spun Filling (Draperies). The mid-weight fabrics include: #266, Spun Viscose Challis; #L-61, Handkerchief Linen; #777, Spun Dacron, T-54, Polyester; and #530, Wool Challis.

The pretreatment of the samples consisted of washing, rinsing, drying, and ironing. Reference test methods for this procedure are AATCC Test Method 124-1984[12] and Test Method 143-1984.[13] AATCC Standard Detergent 124[14] was selected for use as the composition of this detergent is typical. To achieve the critical micelle concentration necessary for cleaning to occur, 90 gms of Detergent 124 was used to wash 1800 grams of sample fabric other than the wool and silk.

All samples were tested for the presence of starch using AATCC Test Method 103-1984.[15] Both the Cotton Batiste #435 and the Cotton Print Cloth #400 (used as a representative, mounted object) were found to contain starch and so were given a treatment with alpha-amylase for the removal of the starch prior to washing.

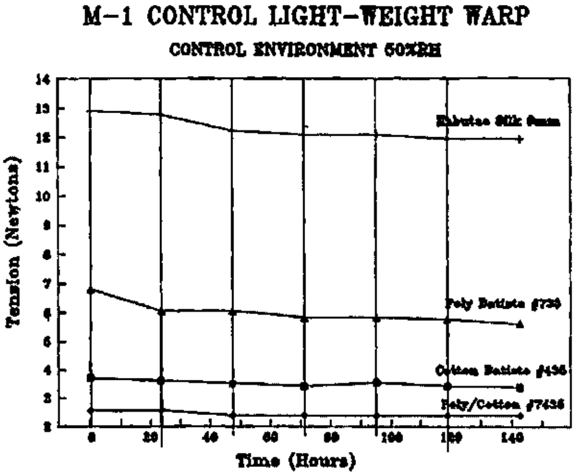

Fig. 3

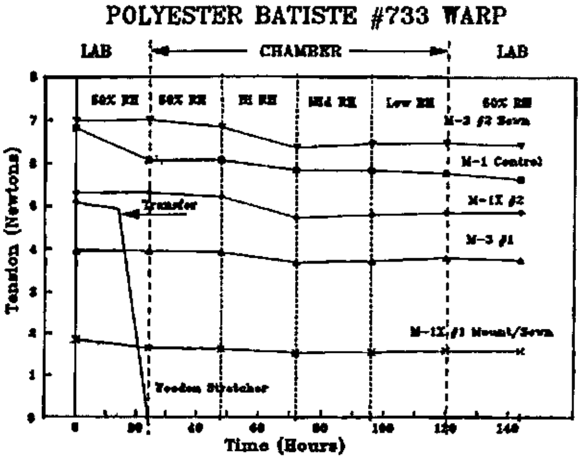

Fig. 4

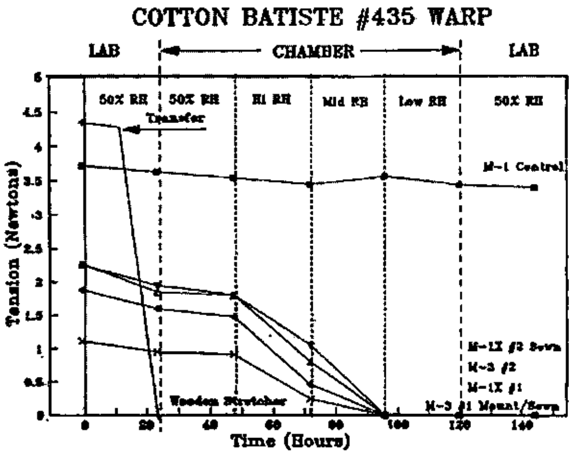

Fig. 5

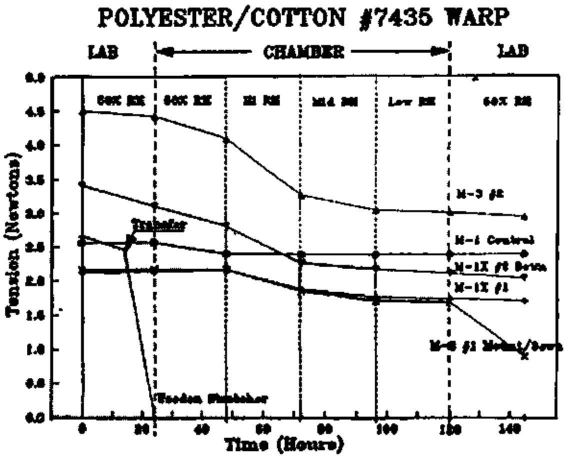

Fig. 6

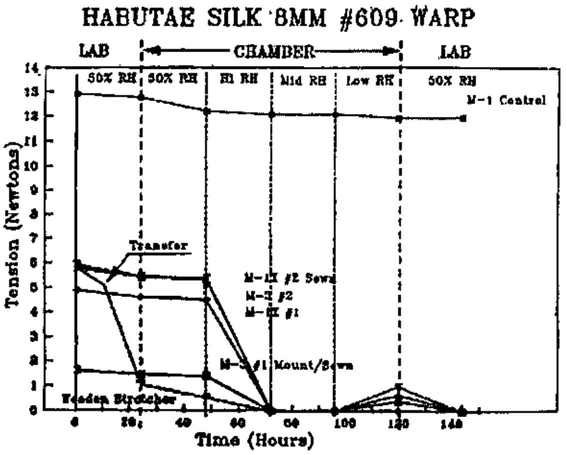

Fig. 7

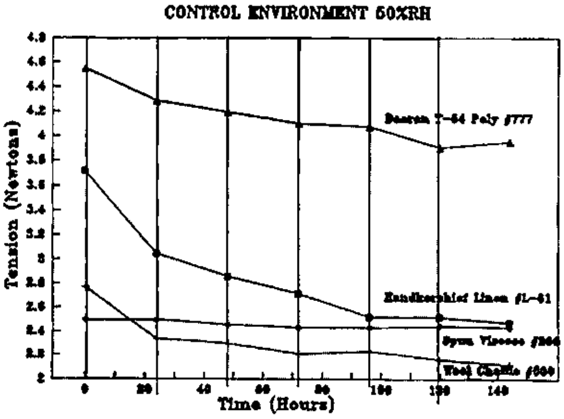

Fig. 8

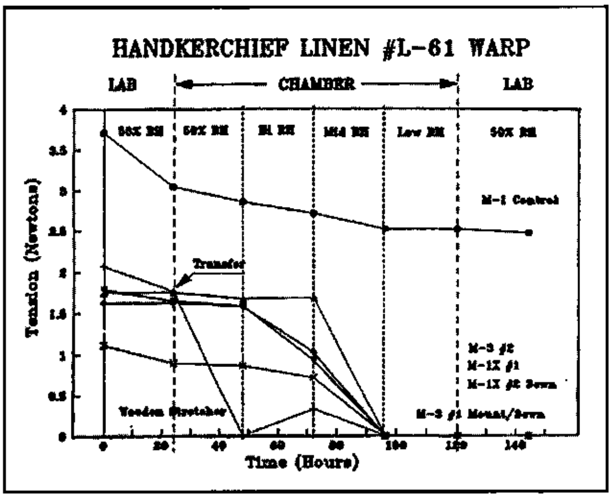

Fig. 9

Wool scouring was done in accordance with AATCC Test Method 99-1988.[16] Scouring of the silk was performed as outlined in a silk degumming procedure compiled by Mary Ballard from the works of Carboni, Howitt and Trotman.[17] In view of the changes of the end and pick counts of the cellulosic fabrics due to washing and drying, it was considered necessary to process all the samples with an aqueous pretreatment.

In this particular study, all supplies and equipment were housed at the Conservation Analytical Laboratory of the Smithsonian Institution. The fabrics and threads were stored in the textile laboratory in a standard condition of 70°F and 50 per cent relative humidity, ± 2, in order that equilibrium could be maintained in this controlled atmosphere. Hygrothermographs were used to record the temperature and relative humidity fluctuations.

The assessment of dimensional change

Warp and weft counts were taken at the tension reading sites employing a Lowinson's Thread Counting Micrometer before and after pretreatment, after stretching, after sewing or transfer, at the end of the humidification cycle, and after removal from tension. In this manner any changes in the fabric geometry could be monitored and the percentage of stretch at that point determined.

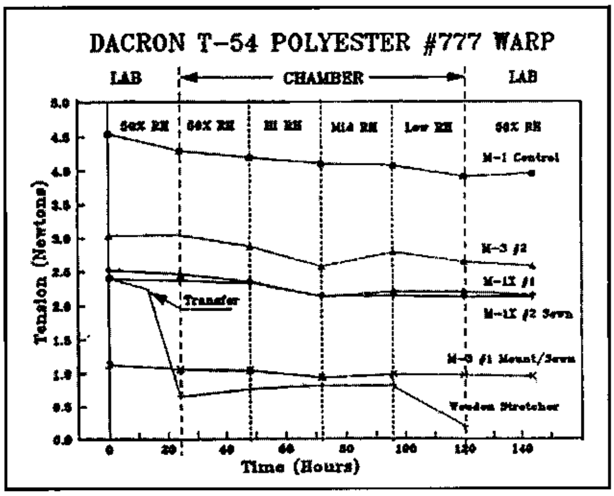

Fig. 10

Samples of each of the eight fabrics selected were subjected to fluctuations of relative humidity inside the control chamber over the period of seven days. Tension measurements were taken at specified intervals. The chamber maintained a humidity cycle synchronised to begin with the maintenance of the Belfort Hygrothermograph each Monday.

On the first and second days the frames were outfitted with new substrate samples (Fig. 2). These stretched substrates were allowed to relax and be retensioned before being placed into the control chamber. After the reading on the third day, pans of water were placed in the control chamber to raise the relative humidity to approximately 90 percent or greater. The tension was read the following day. The cover of the chamber was lifted off and the pans of water were removed in order to reduce the humidity. The cover was then replaced. Tension readings were taken on the fifth day after the humidity had dropped to around 50 per cent. Trays of silica gel were then placed in the chamber. The tension level after desiccation was read on the sixth day. At this point the frames were removed from the chamber and left overnight to return to standard condition. A final tension reading was taken and then the frames were prepared for the next cycle of samples.

A plexiglass chamber, 121.9 x 93.98 x 60.9cm, was built to house the five strainers. Metal Newman Roller Frames with variable tensioning devices were chosen as strainers to stretch the sample fabrics so that an even tension could be achieved.

Of these five strainers, one of the M-3 roller frames, one of the M-1X roller frames, and the wooden stretcher were each outfitted with the same fabric sample substrate. The purpose of this section was to observe tension changes due to fluctuations of relative humidity and how those changes varied from strainer to strainer.

The remaining M-3 roller frame and the remaining M-1X roller frame were outfitted with the same fabric sample substrate as the three strainers mentioned above. A sample artifact of TestFabrics Incorporated Cotton Print Cloth was mounted and stitched around its perimeter to one of the strainers. The remaining strainer was stitched with a combination of zigzag stitching and an all over grid patterning. The purpose of this section was to observe the effects of stitching and the effects of stitched assemblies on the tension of the substrate due to fluctuations of relative humidity.

Six crosses marked in soft graphite pencil were drawn to indicate where the biaxial tension readings were taken. To assess the dimensional changes, warp and weft thread counts and micrometer readings were taken at these sites. These micrometer readings were compared to those of the non-pretreated fabric swatches. Two Newman ST Meters were used to measure bi-directional fabric tension in Newtons.

A 30.5cm square M-1 Roller Frame was outfitted each week with the substrate fabric being observed in the chambers. This frame was placed in the standard

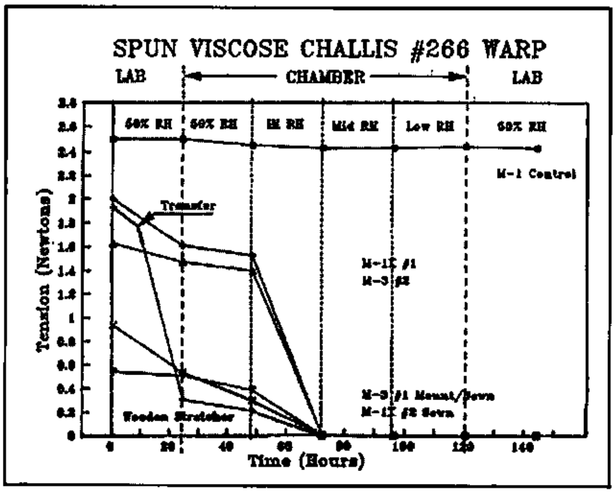

Fig. 11

atmosphere of the textile laboratory. Biaxial tension readings of this frame were taken daily concurrently with the reading of the frames inside the chamber. Warp and weft thread counts with the Lowinson's Micrometer and micrometer readings of the fabric thickness were also measured at the same intervals as the samples inside the chamber.

Eight test fabrics were set up on M-1 Roller Frames to observe their relaxation behavior over a longer period of time at a constant temperature ad humidity. This test was maintained in the controlled environment of the ~~textile labor~~atory at the Conservation Analytical Laboratory. Biaxial tension readings were taken weekly for five weeks. Warp and weft thread counts were taken before and alter the five week period.

The discussion and results of study

It was predicted that the synthetic fabrics would retain tension more evenly than the proteinaceous or the cellulosic fabrics. The average amount of tension lost among the test samples was determined within each fibre group. This average loss was then compared among fibre groups in order to determine the safer materials for use in conservation constrained mounting assemblies.

To help clarify this study, the relationship between these tension readings and tension readings in their context within the silk screen industry should be mentioned. Generally fabrics tensioned by hand fall within the range of 8 Newtons to 10 Newtons. Fabrics tensioned for use by the silk screen industry generally fall within the range of 12 Newtons to 22 Newtons. The accurate lower end of this tension meters capacity is 7 Newtons.

The one-week study

This study found that the weft samples generally behaved similarly, or were only slightly inferior to their respective warp sample counterparts. Tension in these sample fabrics tended to fall off faster in the weft direction and did not reach the beginning tensions achieved in the warp direction. In the interest of simplicity for this discussion, only the warp samples have been compared.

The performances of the light-weight control samples are compared in Figure 3. Alter initial tensioning and a retensioning, the tension at the first point on the graph was determined. With the exception of the Cotton Batiste, all the light-weight samples exhibited a further decline in tension over the period of the two following readings. After the third reading, all the samples, in the stable environment, appeared to maintain a fairly constant tension.

The reason for the apparent evenness in the tension of the Cotton Batiste, in the light-weight samples, as well as the Spun Viscose and Wool Challis, in the medium-weight samples, is due to the necessity of over-tensioning in the weft direction. These samples needed to be over-tensioned in order that an initial tension level could be obtained that would give measurable readings over the course of the humidity cycle within the chamber.

The tension of the Polyester Batiste, shown in Figure 4, appears to stabilise after the first three readings. This sample is virtually unaffected by the fluctuations of the humidity cycle; the slight changes in tension are most likely due to cold flow.

Comparing the control samples in Figures 3 and 8, the degree of tension loss is roughly similar. Both the Cotton Batiste (Fig. 5) and the Habutae Silk (Fig. 7) are drastically affected by the fluctuating humidity cycle. The Polyester/Cotton blend (Fig. 6) displays a loss of tension that is not nearly so severe as that of the unblended natural fibre fabrics. It is interesting to note the slight regain of tension upon desiccation of the natural protein fibre (Fig. 7). This is also in evident in the medium-weight protein fibre, Wool Challis (Fig. 12).

In the constant environment the control samples of the medium-weight category (Fig. 8), the category from which support mounting fabrics are generally chosen, did not vary greatly from the behavior of the light-weight samples. With the unexpected exception of the Spun Viscose sample, the decline in tension does not appear to even out. In comparison within the medium-weight samples, the linen displays a loss of tension greater than any of the other three samples. The medium-weight polyester behaves little

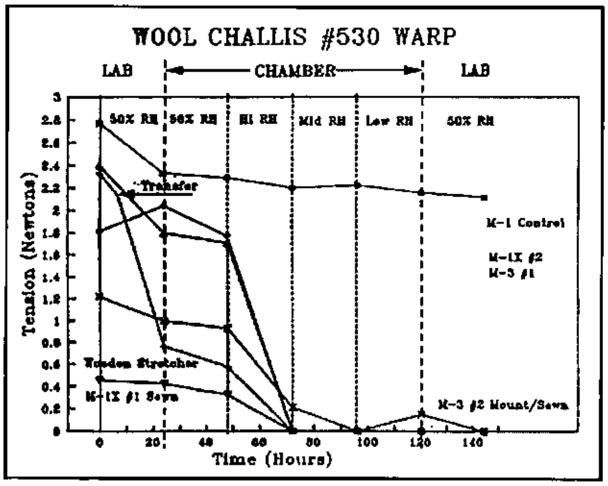

Fig. 12

better than the wool under constraint within the controlled environment. In wool one expects this tension loss, due to its elasticity. The loss of tension in the medium-weight polyester is most likely due to fibre-slippage within the staple yarns.

When subjected to the humidity cycle, the behavior of the samples of the medium-weight category is quite similar to the behavior of the light-weight samples. Again, after an initial loss of tension over the course of the first three readings, the Dacron Polyester T (Fig. 10) began to even out. Both the Spun Viscose (Fig. 11) and the Wool Challis (Fig. 12) display a drastic loss of tension due to high humidity. As noted previously, the protein fibre shows a slight regain in tension upon drying. This appears to also be the case in the Dacron sample. The Handkerchief Linen (Fig. 9) maintained its initial tension setting in a manner similar to the Dacron Polyester (Fig. 10) during the first three tension readings. With the introduction of high humidity, the linen evidenced a slight rise in tension. This regain of tension in the linen was lost and surpassed upon a return to a mid-range humidity.

Neither the presence of stitching, the second objective, nor of a stitched artifact in assembly, the third objective, drastically altered the way the constrained substrate fabric behaved while under tension. Depending upon the nature of the substrate, the stitching thread, and the 'sample artifact', there were very different reactions of the three components after removal from tension.

The results of the fourth objective, the observation of tension changes due to the construction of the frame, was not statistically conclusive. The heavier gauge metal frames (the M-3 Frames) appeared to maintain their dimensional stability better than the lighter gauge metal frames (the M-1X Frames). However, these tests were insufficient to definitively make that determination. When put under tension, a distinct bowing of the long shafts of the light-weight, M-1X Frames could be observed. The severity of this bowing was increased with increases of tension. The tension readings and the observations indicate that it is more likely that differences in tension would occur when using the lighter weight frame rather than the heavier weight frame in these particular dimensions.

When comparing the ability to maintain a constant tension on the metal frames with that same ability on wooden stretchers, one must consider the distinct properties of the materials. Again, the tests were insufficient to make a determination of this matter by the tension readings alone. When considering swelling and shrinkage due to moisture, the use of a metal frame inherently indicates a more stable tension due to the fact that the metal is much less affected by the presence of moisture than is a wooden stretcher.

What did become the most measurable and important part of this objective was how tension was affected by the transference of the substrate from one stretcher to another. In Figures 3–7 and Figures 9–12 the effect of transferring a substrate under tension on one M-3 Frame to a wooden stretcher was examined. This transfer was carried out by attaching the fabric under tension to the wooden stretcher with push pins. The tension on the first frame was carefully removed and the loose fabric turned to the back of the wooden stretcher attached with Monel staples. The push pins were then removed. In every instance there was a marked loss of tension immediately after transfer.

Due to the constraints of time, a comparison of aluminium and plexiglass strainers could not be made. The literature of the silk-screen industry indicates that the loss of tension observed when transferring stretched substrates from one frame to another can be avoided. This is accomplished by the use of an adhesive to affix the substrate to the final metal frame. Silk-screens produced by this method have been proven to provide adequate strength and clarity of registration, however, there is a loss in the number of printing repeats as compared to the retensionable type metal frames.

The assessment of compatibility

The fifth objective, the assessment of the compatibility of the support fabrics, was carried out as described by Oddy. As was expected, the wool outgassed causing corrosion of the metal strips. The remainder of the test fabrics proved negative. It can be concluded, therefore, that the wool cannot be used, but the other fabrics should prove not to be a problem if used for constrained substrates.

The five-week study

The five-week study of the constrained substrate fabric samples proved to substantiate the findings of the one week studies. The largest drop in tension occurred between the initial tension reading and the second reading taken after seven days under tension in the controlled environment. In actuality, as was observed in the one week samples, the major drop in tension occurred within the first two or three days of the initial tensioning.

The tension in both the warp and the weft directions of the light-weight samples appeared to remain fairly constant throughout the remainder of the study after the initial drop of tension during the first week the cotton sample developed breaks in the fabric substrate after the fourth tension reading. These breaks proved to be sufficiently severe as to render this fabric sample untensioned. In view of the weakness of the fabric as observed during the setting-up of the frames, this occurrence was considered to be characteristic rather than unique.

The tension readings of the warp and weft of the medium-weight samples appeared to be less constant than the tension readings of the light-weight samples. Generally this would not be considered surprising due to the inclusion of rayon and wool fabrics in that category. What is surprising is that the tension readings of the rayon and wool fabrics are more consistent than the tension readings of the polyester or the linen. Although the tension of the polyester does appear to even out, the tension of the linen continues to fluctuate.

Conclusions and recommendations for further study

The main conclusions are that at constant relative humidity, the tension of the substrates remains fairly constant under constraint regardless of the type of fabric. Natural and man-made fabrics lose their tension drastically compared to the synthetic fabrics when affected by high relative humidities. However, the use of light-weight fabrics appears to provide a more consistent tension than the medium-weight fabrics.

Even with a loss of tension due to humidity, the construction of the substrates is only slightly affected while under constraint. In these assemblies, the problems presented themselves when the substrate fabrics were untensioned. Like-stiffness of fabrics and sewing threads is more important to compatibility in a assembly than like-fibre characteristics.

The consistently large drop in tension over the first few days indicates that when constructing fabric mounts, it is advisable to wait before the attachment of an artifact. In other words, after tensioning the fabric substrates onto a strainer, it is advisable to wait until the initial tension loss has occurred. After the tension of the constrained mount has evened out, then the object can be attached to the substrate.

Lastly, the concept of transferring mounted artifacts from strainer to strainer while maintaining a constant tension is questionable.

The observable and measurable properties of such a small test sampling can only be an indication of the results of a larger sampling. The measuring devices used for this test can only make gross evaluations. A suggestion for further study would be to redo the study with more precise measuring equipment. A more precise observation of the exact relative humidity where tension begins to evidence decline would be of great interest. A compliation of data from both the biaxial and uniaxial methods of testing of these samples would also be of great interest.

A suggestion for future study would be to test a greater number of samples and a wider range of fabrics over longer periods of time. The effects of multiple cycling on the fabric substrates should also be examined. It was not within the time constraints of this study to observe the effects of temperature. Future studies should examine both the effects of temperature changes at a constant relative humidity and the effects of varying both temperature and the relative humidity simultaneously.

The Mecklenburg method of sample observation permits the study of relatively small uniaxial samples. Small textile samples of artifacts could be studied with this method, although, in most cases, random sampling would not be possible. Where random sampling is impossible, an accurate measurement of an artifact's behavior can only be estimated. To overcome this limitation, artificially aged samples might be used instead. However, it must be remembered that artificially aged samples provide only a limited generalisation of the behavior of the artifact that they attempt to represent.

Correlation between the results of these tests would be of great interest to the textile conservation field. In this way, textile conservators would have additional fabric model data by which to select the most suitable fabric type for constrained fabric mounting devices.

Notes

[1] Brenner, F. C. and Chen, C. S., 1965 'Mechanical Behavior of Fabrics. Part III: Effect of Density of Construction on Recovery from Deformation'. *Textile Research Journal* 35: 587–91.

[2] Klein, W. G., 1959 'Stress-Strain Response of Fabrics Under Two-Dimensional Loading. Part I: The FRL Biaxial Tester'. *Textile Research Journal* 29: 816–21.

[3] Peirce, F. T., 1937 'The Geometry of Cloth Structure'. *Journal of the Textile Institute* 28: 45–96.

[4] Peirce, F.T., 1947 'Geometrical Principles Applicable to Design of Functional Fabrics.' *Textile Research Journal* 17: 123–47.

[5] Freeston, W. D. jr, Platt, M. M., and Schoppee, M. M., 1967 'Mechanics of Elastic Performance of Textile Materials. Part XVIII: Stress-Strain Response of Fabrics Under Two-Dimensional Loading'. *Textile Research Journal* 37: 948–74.

[6] Mecklenburg, M. F., 1982 *Some Aspects of the Mechanical Behavior of Fabric Supported Paintings*. Report to the Smithsonian Institution.

[7] Hedley, G. A., 1988 'Relative Humidity and the Stress-Strain Response of Canvas Paintings: Uniaxial Measurements of Naturally Aged Samples'. *Studies in Conservation* 33: 133–48.

[8] Berger, G. A, and Russell, W. H., 1988 'Practical Applications of Stress Tests'. In *Preprints of Papers Presented at the Sixteenth Annual Meeting, New Orleans* to The American Institute for the Conservation of Historic and Artistic Works (AIC).

[9] Berger, G. A, and Russell, W. H., 1986 'Investigations into reactions of Plastic Materials to Environmental Changes. Part I: The Mechanics of the Decay of Paint Films'. In: *Studies in Conservation* 31: 49–64.

[10] Ibid.

[11] Oddy, W. A., 1973 'An Unsuspected Danger in Display'. In: *The Museums Journal* 73: 27–28.

[12] American Association of Textile Chemists and Colorists (AATCC), 1989 'AATCC Test Method 124-1984: Appearance of Durable Press Fabrics after Repeated Home Laundering.' In the *1989 Technical Manual of the American Association of Textile Chemists and Colorists.* Research Triangle Park, North Carolina: American Association of Textile Chemists and Colorists.

[13] American Association of Textile Chemists and Colorists (AATCC), 1989 'AATCC Test Method 143-1984: Appearance of Apparel and Other Textile End Products after Repeated Home Laundering.' In the *1989 Technical Manual of the American Association of Textile Chemists and Colorists.* Research Triangle Park, North Carolina: American Association of Textile Chemists and Colorists.

[14] American Association of Textile Chemists and Colorists (AATCC), 1989 'AATCC Detergent 124.' In the *1989 Technical Manual of the American Association of Textile Chemists and Colorists*. Research Triangle Park, North Carolina: American Association of Textile Chemists and Colorists.

[15] American Association of Textile Chemists and Colorists (AATCC), 1989 'AATCC Test Method 102-1984: Bacterial Alpha-Amylase Enzymes Used in Desizing...' In the *1989 Technical Manual of the American Association of Textile Chemists and Colorists*. Research Triangle Park, North Carolina: American Association of Textile Chemists and Colorists.

[16] American Association of Textile Chemists and Colorists (AATCC), 1989 'Wool Textiles: Relaxation, Consolidation and Felting.' In the *1989 Technical Manual of the American Association of Textile Chemists and Colorists*. Research Triangle Park, North Carolina: American Association of Textile Chemists and Colorists.

[17] Ballard. M. W., 1990 *Pre-Metalised Dyes on Silk. Degumming*. Photocopy handout provided for the Dye Work shop offered at the Conservation Analytical Laboratory, Smithsonian Institution, Washington, DC.

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