TESTING STRUCTURAL PROPERTIES OF FABRICS

AUTHOR: J. DEAN - McLean Wade & Partners Pty Ltd
Brisbane

SYNOPSIS

This paper discusses the need for reliable biaxial test data on fabric properties. The available literature on biaxial fabric testing is reviewed and details are given of a fabric testing machine to be developed at Queensland University of Technology.

DEVELOPMENT OF A MACHINE FOR TESTING STRUCTURAL PROPERTIES OF FABRICS

1. INTRODUCTION

The use of coated woven fabrics as a roof membrane has become a competitive and popular alternative to more conventional systems. Developments in fabric technology in the areas of strength. durability and fire resistance have given way to a wider acceptance of fabric structures as a reliable option for many applications. These developments have also produced a wider variety of materials available for use as tension membranes. In order for fabric roof systems to be cost effective the fabric system must be light-weight and simple when compared to other systems. By using high strength fabric membranes as both a cladding and structural element, large spans can be achieved. providing both a light weight and reliable roofing solution.

In most applications the essential end user requirement for coated and laminated fabrics include the following: water impermeability, high strength, high strength when wet. good tear resistance, high seam adhesion, and resistance to U.V. degradation. rot, mildew and common chemicals. Flexibility and low creep under load are also desirable properties from the erection and maintenance point of view. Sane of the above properties are provided by the coating or laminating film while others, mainly strength and dimensional stability are satisfied by the fibre and fabric construction.

1.1 AIM

The aim of this paper is to review the available literature on fabric testing with a view to developing a testing device suitable for determining the engineering properties of fabrics used in tension membrane structures. The machine will be constructed as part of a Masters study programme being undertaken by the author at Queensland University of Technology. McLean Wade and Partners Pty Ltd of Brisbane are acting as a major sponsor of the project.

1.2 BACKGROUND

Light weight wide-span structures employing coated fabrics are usually pre-tensioned to achieve a wrinkle free surface and a stable form. This pretensioning is done by edge tensioning via catenary cables, clamp plates. air pressure. etc. In most cases the surface is patterned to have double curvature and as a result the fabric material is stressed in two directions, or biaxially. Uniaxial stress states occur very rarely and then only momentarily in a wrinkle-free membrane. In addition to prestressing, applied loads such as wind. snow, water and maintenance also produce stresses within the surface membrane which act biaxially. This occurs as the surface shape changes to accommodate the load and redistribute it to the supports.

Often the tests performed on fabrics are uniaxial because of the difficulty and expense of biaxial testing. Unfortunately a satisfactory relationship between uniaxial and biaxial strength has not been established.

The importance of a good understanding of biaxial properties must not be underestimated. In the analysis of membrane structures the designer considers such things as stresses in the membrane, reactions to supporting structures, and surface deflections. Each of these critical aspects is influenced by the fabric properties used in the analysis. The amount of compensation used at the time of patterning has a critical impact on the successful fabrication and installation of the structure. Therefore, in order for designers and fabricators to have confidence in the design, performance and reliability of the membrane structure an accurate knowledge of biaxial properties is essential.

1.3 SCOPE

The scope of this project is limited to tests focusing on fabric strength and stretch properties. A machine with these testing capabilities may be usefully employed in tests for determining many of the other properties listed above.

One of the most important attributes of a fabric for designers and fabricators is the load deflection relationship. The load deflection relationship considered should not be simply for plain fabric but for the fabric within a structure. that is for the same stress state, fabric alignment, and seam arrangement which exist in the real structure. The real structure cannot be modelled except by building, instrumenting and testing a full scale prototype, which is only warranted for large scale multiple module projects like that of the Haj Airport Terminal, in Saudi Arabia. The best approximation available to most designers is computer based finite element models. into these models the designer inputs material properties which, for a fabric about which little is known. must be approximated or guessed. More realistic measures of fabric properties within a structure can be obtained by including welds and doublers in a test piece. Additional refinements to compensation factors can be achieved by duplicating, in a test piece, the stress states that exist in the computer model of the structure.

The testing machine must be capable of testing the range of fabrics regularly used and those which are expected to be used in the future within the Australian market. By providing biaxial and uniaxial test results the machine will be useful to fabricators and designers, both of whom have needs for information on fabric performance under these stress states.

An additional property of interest to the author is the shear modulus of biaxially stressed fabric. The sensitivity of computer models to variations in shear modulus has yet to be fully established. However preliminary sensitivity studies have shown that the use of a reasonable shear modulus can reduce the calculated stresses in a structure by up to 15%. Therefore the facility to apply shear loads to a fabric specimen is a desirable feature for a proposed testing device.

1.4 MATERIALS

Most fabric for architectural purposes is made from polyester or glass fibres. These fibres are first spun into yarn which is then woven into cloth. The yarn consists of a bundle of continuous filaments with a slight twist. Plain weave is commonly used for light synthetic fibre cloth and for glass cloth. Panama weave. where the threads are woven in two's or three's or even four's, is often used for heavier cloth giving a flatter surface for coating. Another base cloth configuration is knitted weave, where the warp threads are laid over the weft threads and knitted in place with a third lighter yarn. After weaving and coating the warp yarns are usually straight and weft yarns undulate. In woven fabrics, under load in the weft direction these yarns will straighten and the warped yarns will undulate, a process known as crimp interchange [Liddell (3)].

The most common coating material for laminated fabrics is PVC. The plasticised PVC is made up of a number of different materials blended together. Each manufacturer has their own recipe for this blend and therefore most products perform differently. The durability of P.V.C. coating can be improved by adding a weathering layer of either PVC with a polymeric plasticiser, acrylic compounds. a tedlar laminate or a P.V.D.F. coating.
Glass fibre cloth is usually embedded in a teflon matrix producing a product which has high strength and good dimensional stability.

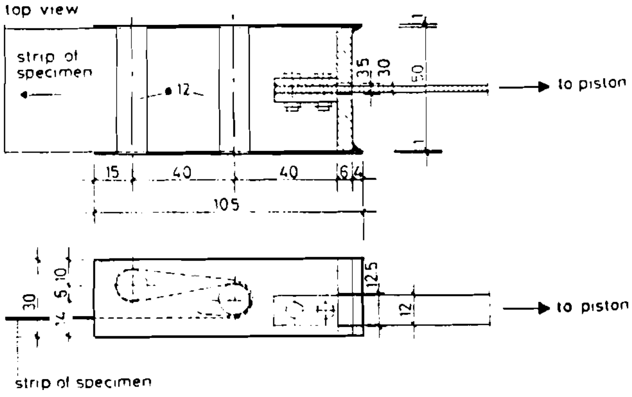

Figure 1. Reinhardt's self fixing clamp.

2. CURRENT LOCAL PRACTICE

As previous1y stated, successful fabrication and installation relies heavily on the use of appropriate compensation factors for the production of cutting patterns. In the absence of comprehensive test data, designers must **formulate** a set of material properties and canpensation factors for the fabric specified. Fabricators who have used different batches of fabric on the same job have found that their properties often vary. This is a major reason for the need for a means of obtaining fabric properties locally. Most manufacturers supply various test results for their products. however. the details and procedures of these tests often remain unknown. In many cases the test data is several years old leaving the designer with limited confidence in it's accuracy. This is especially true if properties must be interpreted or extrapolated from the information available. Suitable working **compensation** factors are generally a composite of best guess seasoned with hindsight. There is clearly roan for development in this area of the industry.

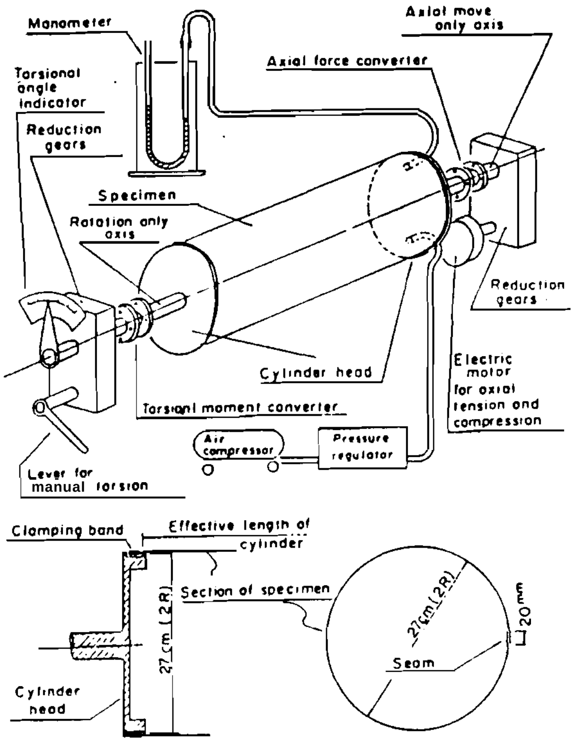

Figure 2. Torsion-specific testing device (after Hirokazu et al)

3. LITERATURE REVIEW

3.1 TEST METHODS

Two types of tests are used to determine strength and stiffness properties for membranes: uniaxial and biaxial.

In the literature considered different types of biaxial testing appeared: bursting. planar and cylindrical. Each test method is mentioned below with reference to the studies reviewed.

3.1.1 BURSTING

Reinhardt (6) describes bursting tests as the most simple biaxial-loading test. The test uses a circular membrane specimen which is clamped along the edge. This flat membrane is deformed by lateral air or water pressure into a spherical shape and the pressure is increased till the specimen bursts. A relation between pressure and deflection gives the bursting strength of the fabric.

The disadvantages of this procedure are that only small specimens can be used, the ratio of stresses in warp and weft direction cannot be varied, and the angle between warp and weft direction changes during testing. 'This test also has the disadvantage of not being able to apply shearing loads to the specimen. Additionally since fabrics are anisotropic materials. the deformed figure is not exactly a sphere therefore. the assumptions on which the calculations of stress and strain are based are not completely correct.

Reinhardt reports that results of the bursting tests of coated fabrics show that the bursting strength reaches only approximately 80 percent of the mean of the uniaxial strength in weft and warp direction.

3.1.2 UNIAXIAL

Uniaxial tests on fabric are widely used in many areas of the fabric industry and standards exist for these tests. Usually 50 inn wide strips are clamped between jaws and tested to destruction. Fran these tests uniaxial ultimate strengths and load-deflection characteristics can be determined for both warp and weft directions. Uniaxial results are used for classifying different materials but are of little value for designers and fabricators.

3.1.3 PLANAR BIAXIAL

Hirokazu et al. who also developed a cylindrical tester, initially developed a planar tester (1) to determine fabric biaxial deformation properties. One problem associated with planar biaxial testing is to determine an appropriate clamping device which does not influence the strains in the test piece. Reinhardt and others have overcome this problem by using slitted cross shaped test pieces. Reinhardt's machine uses individual self-clamping mounts (fig. 1) for each slitted section and is composed of a rigid frame with four hydraulic pistons on each side which are transversely movable and independently adjustable. The specimen had a square field of 200mm x 200mm and four strips on each side which were fixed to the pistons. A photographic record of loading was used to determine strains. Other methods of recording strains are available including electronic displacement transducers, large-displacement strain gauges, and other fluid based methods.

Reinhardt produced biaxial failure in an open weave P.V.C. coated polyester fabric at loads equal to it's uniaxial strength.

3.1.4 CYLINDRICAL BIAXIAL

Cylinder testing is performed by axially loading and pressurising a sealed cylinder of fabric, shear can be introduced in the fabric by applying torque to one end of the cylinder. The three forces can be varied independently, allowing almost any stress state to be imposed on the test piece.

One feature of cylindrical tests on fabric is that a seam usually cannot be avoided except for specially woven circular testing fabrics. Therefore the test specimen must consist of a cylinder with one seam, or more if symmetry is required. When seams are present the stress-strain behaviour is influenced by the seams and, strictly speaking, the properties of a composite material are investigated and not those of the fabric alone.

Hirokazu et al (2) produced a cylindrical testing machine solely for the purpose of investigating the shear properties of coated fabrics (fig. 2.). In their tests no attempt was made to perform ultimate tests, which resulted in a lightweight device with a limited range for testing biaxial properties. Mott et al (4 & 5) on the other hand produced a machine with capacity to biaxially rupture a P.T.F.E. coated fibreglass fabric with an ultimate uniaxial strength of 190 kN/m (9500 N/50mm). This machine also had the ability to simultaneously apply shear loads.

3.2 DISCUSSION

Reinhardt claims that planar tests produce the best results for the calculation and measurement of biaxial stress and strain. This claim is based on the fact that a cylindrical test piece must include a seam thus making it a composite of plain fabric and seamed fabric. It is desirable from the point of view of this study that the test piece does include seams. Because of this, a cylindrical tester has no disadvantage provided that seam material is not over represented in the width of fabric being tested.

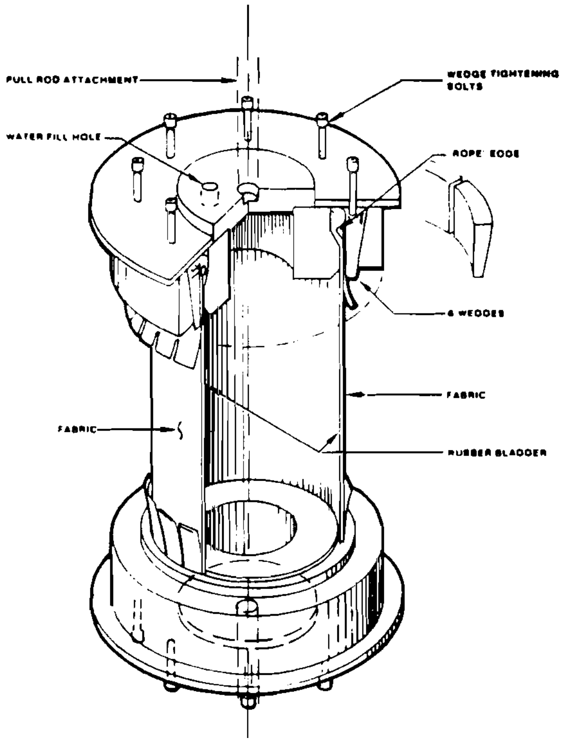

Figure 3. Schematic of test cylinder showing clamping after Hott et al.

The good correlation between biaxial and uniaxial strengths achieved by Reinhardt show the need for careful attention to fixing details and edge effects. No authors. other than Reinhardt discussed this aspect of their testing, therefore it will be necessary to develop and perfect a system of clamping. The system used by Mott et al appears to have been quite satisfactory.

4. PROPOSED MACHINE

The proposed machine will follow the lines of Mott et al and have the ability to apply independent biaxial loads and torsion. It is intended that the machine be able to test fabrics with an ultimate strength of 150 kN/m. This is judged to be adequate for the Australian industry.

The test piece will be a cylinder 318 mm diameter and 600 mm long plus rope edge or clamping allowance as required. In order to model the fabric within a real structure it is anticipated that seams in the range of 20 to 40 mm be used. Depending on the fabric being tested and the type of clamping detail used, a rubber bladder may be used to facilitate pressurization. A clamping mechanism similar to that used by Mott et al (fig. 3.) will be developed. Special attention will be given to the problem of eliminating "bedding in" of the clamping device during the actual test so that strain measurements are not influenced.

4.1 FURTHER DEVELOPMENT

The proposed machine will have potential for use with possible future studies on many aspects of fabric technology. Topics of studies in which the testing machine will be useful would include: aspects of seaming, specific fabric performance, weatherability and durability under various exposure conditions, dynamic response. studies of damaged fabric, and performance under temperature extremes,

5. CONCLUSIONS

It has been shown that current design practice has a deficiency of reliable information on fabric properties. The variance between batches of fabric has been revealed as one reason for more information on fabric properties. The importance of biaxial properties to the designer and fabricator has been established. The available literature on testing machines has been reviewed with a brief discussion of the merits of the various methods. A machine has been proposed which will benefit the membrane structure industry as a source of vital information on fabric properties. It is believed that the availability of this information will enhance the ability of designers and fabricators to promote membrane structures as a desirable, acceptable, affordable and viable solution for covering Australia.

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