Preparing and Developing of the Biaxial Tensile Testing Machine of Membrane Structure

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ABSTRACT
A new-style machine that can measure the mechanical character of membrane material is introduced. In order to solve the bottleneck problem in the field of membrane material-measurement of the mechanical character of membrane material, it develops this machine. The background, theory, structure, function and characteristic of the testing machine are expounded. The testing result by an example is also expounded.

PAPER

1. Research background
From the beginning of the Shanghai stadium, there has been about ten years in China of modern membrane structure. Because of its modern article expressive force and the different mechanical performance to traditional structure, research and application of membrane structure has been recognized by architectures and researchers. Theories including analysis of forming, load and clipping has been developed to a comparative level. The designing software of membrane structure also has been applied in extensive field. The modern membrane material is made of grass roots, coats and surface layer. The grass roots, which decide the mechanical characters of membrane material, are weaved by textile fibers. Coats and surface layer, which can clean there selves, resist pollution and are perdurable, protect grass roots. By the development of membrane structure, the lack of research of mechanical characters of membrane material has been one of the factors that restrict the development of membrane structure in China. Nowadays in China, there are not testing standard for test mechanical characters of membrane material and the international testing standard include Germany, American, British and Japanese standard. So the development of research of testing method and testing machine for membrane material has been a bottleneck of the development of membrane structure domain. The civil engineering school of Tong ji University of Shanghai China progress the basically testing research of modern membrane material and impolder the biaxial testing machine. This testing machine can test the stretching strenght, elongation, avulsional strength, modulus of elasticity for single axis and biaxis and other mechanical characters.
2. Testing theories of biaxial testing machine

2.1 The stretching strength and elongation

2.1.1 Testing method

The stretching strength, elongation and load-displacement curve can be gained by using single axis test.

\[ \varepsilon_b = \frac{L_b - L_0}{L_0} \% \]  

Elongation can be expressed as:

- \( L_b \) — measured length when membrane crack
- \( L_0 \) — availability length

2.1.2 Size of specimen

The specimen is oblong, whose total length \( L > 300 \text{mm} \), breadth is about 50mm, the length of middle part of specimen \( L_0 > 200 \text{mm} \). The shape of testing sample was showed in figure 1 and the testing standard for single-axis testing of membrane material was showed in table 1.

![Figure 1. The shape of testing sample for the measurements of tensile strength and extending ratio](image)

<table>
<thead>
<tr>
<th>Testing standard</th>
<th>BS 3424</th>
<th>DIN 53354</th>
<th>ASTM 4851</th>
<th>JIS L1096</th>
<th>ISO 1421</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension of clipping part (mm)</td>
<td>200 ± 1</td>
<td>200</td>
<td>75 ± 1</td>
<td>200</td>
<td>200 ± 1</td>
</tr>
<tr>
<td>Width of sample (mm)</td>
<td>50</td>
<td>50</td>
<td>25.4</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Loading speed (mm/min)</td>
<td>100 ± 10</td>
<td>100 ± 10</td>
<td>50 ± 3</td>
<td>200 ± 10</td>
<td>100 ± 10</td>
</tr>
<tr>
<td>Testing target</td>
<td>( P_f ) (N/5cm)</td>
<td>( P_f ) (N/5cm)</td>
<td>( P_f ) (N/2.5cm)</td>
<td>( P_f ) (N/3cm)</td>
<td>( P_f ) (N/3cm)</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_f ) (%)</td>
<td>( \varepsilon_f ) (%)</td>
<td>( \varepsilon_f ) (%)</td>
<td>( \varepsilon_f ) (%)</td>
<td>( \varepsilon_f ) (%)</td>
</tr>
</tbody>
</table>

Table 1. The testing standard for single-axis testing of membrane material

2.2 Tear strength

2.2.1 Testing method

Presently, the measurement of tearing strength includes the methods as single tongue tear test, double tongue tear test and trapezoidal tear test.

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2.2.2 Size of specimen

The shape of testing sample was showed in figure 2.

![Figure 2. The shape of testing sample of test for tearing strength](image)

2.3 Modulus of elasticity and possion ration

2.3.1 Testing method

The membrane materials usually are in the state of biaxial stress, so the correct method to test the modulus of elasticity is to use biaxial tensile testing machine. This material is not elastic material, but a kind of composite material, which possesses high unlinearity. This material’s modulus of elasticity is effected by exterior condition, and the testing result is very discrete. So the testing modulus of elasticity static value that aimed at the true stress state of the membrane material. It use X style sample and loading on warp and weft direction at the same time with different load ratio (warp: weft=2:1, 1:1,1:2, 1:0, 0:1). And at the same time gather the strain value at the centre of specimen in warp and weft direction. So we can gain the stress-strain curve and compute the material’s modulus of elasticity $E_x$, $E_y$ and possion ration $\nu_x$, $\nu_y$.

2.3.2 Size of specimen

The shape of testing sample was showed in figure 3.

![Figure 3. The shape of testing sample for the biaxial testing](image)
2.3.3 Shear modulus

By using the material’s modulus of elasticity $E_X$, $E_Y$ and poisson ratio $\nu_X$, $\nu_Y$ and $E_{45}$, which is the modulus that warp and tension is 45°, we can compute the shear modulus by using the formula advised by IASS:

$$\frac{1}{G} = \frac{4}{E_{45}} - \frac{1}{E_X} - \frac{1}{E_Y} + \frac{2\nu_X}{E_X}$$  \hspace{1cm} (2)

3. Introduction of biaxial tensile testing machine.

The biaxial tensile testing machine was prepared by Tongji University. It is a new type of machine that can measure many mechanic characteristics mentioned before. The machine is showed in figure 4.

![Biaxial tensile testing machine](image)

3.1 Introduction of theory of machine

The biaxial tensile machine is for the use of testing the modulus of elasticity, stress strength and other mechanical properties of membrane material. By using the electrical machine to bring to bear tensile load to the specimen and using sensor to measure the value of tensile in the course of test, and at the same time using displacement sensor to measure the displacement of specimen, this machine can carry out load-displacement curve at the state of single axis and biaxial from which we can compute the modulus of elasticity, stress strength and other mechanical properties of membrane material. Specimen is X style, which is fixed in the center of the testing machine. The four boundary of specimen are fixed by the clipper and the displacement sensor is fixed in the center of specimen. As equipment that applying load, the servo electrical machine is fixed at the bottom of leading screw, and at the same time, the value of load is recorded by sensor. There is a displacement sensor at the center of specimen which can transfer the value of displacement. Using these data, the software can protract load-displacement curve. Because the two servo electrical machines are fixed in two direction (warp and weft) and can work at the same time, this biaxial tensile machine can make biaxial test and to-and-pro test.

3.2 Performance of machine

3.2.1 Performance in the mass

Power supply: 380v AC drive power.
Scope of measurement: tensile load (0~10000)kN
Speed of test: displacement (6~50)mm/s
Ration of test: 1:1, 1:2, 1:3, 1:4

3.2.2 Read and write of data

Control software: windows 2000, MCGS software
Output of data: the testing curve is outputted on the screen of computer
3.3 structure of machine

The structure of each part is showed in figure 5.

![Structure of mechanical part](image)

(a) view from front                       (b) view from upward

Figure 5. Structure of mechanical part
1-leading screw, 2-fixing unit for leading screw, 3-clip for membrane, 4-fixing plate, 5-displacement sensor, 6-tensile load sensor, 7-installation for load, 8-main frame

3.4 Purpose of machine

As mentioned above, the biaxial tensile machine is for the use of testing the modulus of elasticity, stress strength and other mechanical properties of membrane material in the state of single axis and biaxial. It can make a to-and-fro test and give the to-and-fro load-displacement curve. Some examples about the testing results by using this machine are showed in figure 6.

![Examples about the testing results](image)

(a) Load-displacement curve of single-axis tensile process, (b) Load-displacement curve of single-axis loading-unloading process, (c) Load-displacement curve of biaxial tensile process

4. Epilogue

As mentioned above, the lack of research of mechanical characters of membrane material has been one of the factors that restrict the development of membrane structure. The biaxial tensile machine provide a necessary testing instrument.

References

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