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Biaxial tensile properties and elastic constants evaluation of envelope material for airship

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Abstract: This paper presents an experimental study to determine the tensile properties of the envelope fabric Uretek3216L under biaxial cyclic loading. First, the biaxial cyclic tests were carefully carried out on the envelope material to obtain the stress-strain data, and the corresponding nonlinearity and orthotropy of the material were analyzed. Then, for some determination options with different stress ratios, the least squares method minimizing the strain terms was used to calculate the elastic constants from the experimental data. Finally, the influences of the determination options with different stress ratios and the reciprocal relationship on the elastic constants were discussed. Results show that the orthotropy of the envelope material can be attributed to the unbalanced crimp of their constitutive yarns in warp and weft directions, and the elastic constants vary noticeably with the determination options, as well as the normalized stress ratios. In real design practice, it is more reasonable to use constants determined for specific stress states, in particular stress ratios, depending on the project's needs. Also, calculating the structures with two limitative sets of elastic constants instead of using only one set is recommendable in light of the great variety of the constant's values.

Key words: coated fabric; airship; tensile property; reciprocal relationship; elastic constant; stress ratio

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There has been a considerable interest in stratospheric non-rigid airships as a cost effective alternative to earth orbit satellites for telecommunication and science observation. Due to their greatly expected usage, many countries have plans or real activities to develop high altitude non-rigid airships[1–3]. The envelope, which is made of coated fabrics, is one of the major structural parts in a non-rigid airship[2]. As we all know, a better understanding of the tensile properties of envelope fabrics may significantly reduce levels of uncertainty in the design process of an airship envelope, and the accurate determination of elastic constants is vital to achieve safe and efficient designs of airships. This paper attempts to investigate the tensile properties and evaluate the elastic constants of a coated fabric for an airship envelope under biaxial loading.

In the last two decades, an increasing effort has been made to experimentally study the mechanical properties of coated fabrics of non-rigid airships. Kanga et al. [2] performed uni-axial tests and finite element analyses to obtain effective tensile properties of a film-fabric laminate developed for a stratospheric airship envelope. Huang et al. [4] tested an envelope fabric under biaxial tension loading with a 1∶1 stress-ratio and proposed an analytical algorithm to calculate the elastic constants of the coated fabric using the reciprocal theorem. However, for coated fabrics, values of elastic constants do not meet the reciprocal theorem. They are unconstrained variables, which have been proved by Gosling and Bridgens[5]. Gao et al. [6] carried out a series of tests and obtained elastic constants of the envelope fabrics under mono-uniaxial loading and uniaxial cyclic loading. There have also been studies[3,7–8] focusing on tear propagation properties, reinforcing methods of an opening, and the long term weathering characteristics of envelope fabrics. More comprehensive reviews can be found in Ref. [9]. As we all know, coated fabrics have also been widely applied in large span buildings such as stadiums, gymnasiums, and airport lounges[10]. These kinds of coated fabrics are commonly referred to as "architectural fabrics", whose tensile behaviors have been reported in much literature[10–19]. A more detailed review can be found in Refs. [11, 20].

There are very specific demands on materials concerning airship construction. Envelope fabrics need to exhibit proper properties of strength, weight, air-tightness, weather and ultra violet (UV) stability, conductivity, and non-flammability[9]. Compared with architectural fabrics, envelope fabrics generally consist of different substrates, coatings, and numbers of layers, and thus the fabrics under tensile loading behave rather differently. A typical envelope material is a multi-layer flexible laminate (see Fig. 1). The studies[2–8] of envelope fabrics mentioned above, however, mainly dealt with the general tensile properties of envelope fabrics under mono-uniaxial loading, such as stress-strain diagrams and breaking strength, and rarely touched upon the issue of evaluation of elastic constants of envelope fabrics under biaxial load-

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ing. The interaction of warp and weft yarns (crimp interchange, Fig. 2[21]) results in complex, nonlinear biaxial behavior that cannot directly be inferred from uniaxial testing alone[21], and it is rarely fully quantified due to the paucity of specialist test equipment and test procedures. Furthermore, the lack of understanding of the tensile properties of coated fabrics hinders the utilization of the results of tests in the design of analyses. In other words, the true behavior of envelope fabrics is highly nonlinear, and can only be determined by extensive biaxial testing[21-22]. However, the complex mechanical characteristics under biaxial loading make it difficult to obtain accurate elastic constants[10, 23].

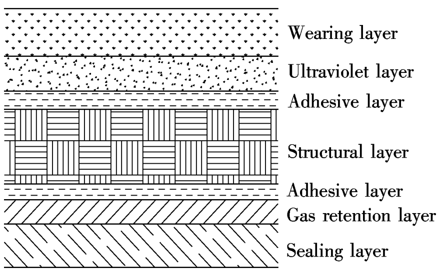

Fig. 1 Typical envelope fabrics layout

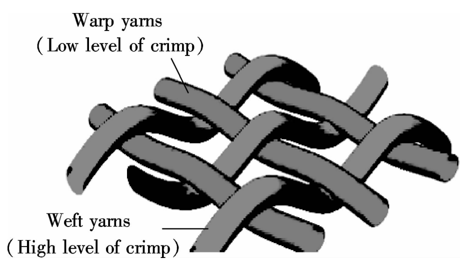

Fig. 2 Crimp interchange mechanism[22]

The envelope material Uretek3216L is a high-tech coated and multi-layer laminated fabric, whose substrate is polyester yarn plain-weave textile, its coating is polyurethane and its surface finish is polyvinyl fluoride (PVF), called tedlar®. This envelope fabric shows 280 g/m^2 areal density with a thickness of 0.38 mm, and is widely used in medium sized airships.

This paper presents an experimental study on the tensile properties of the envelope fabric Uretek3216L under biaxial cyclic loading. The objective of this article is to understand its tensile properties and determine the proper elastic constants for the envelope fabrics by the tests under biaxial loading. Some suggestions are offered to utilize these constants in design or analysis of the airship structures. Based on this study, we can further study the behaviors of airship structures and achieve reasonable design, analysis and cutting pattern for the airship.

1 Experimental Program

1.1 Specimens

The biaxial tests were performed on cruciform specimens with their arms aligned to the warp and weft directions of the fabric, according to the geometry depicted in Fig. 3. The specimen is with a cross area of 160 mm × 160 mm, and an effective cantilever of 160 mm. Three slits were cut in each arm of the specimen in order to obtain a homogeneous tensile stress in the center of the specimen, even for large deformations. Coated fabrics are known to have a significant level of variability across the width of a single roll due to bowing or skewing of the fabric during manufacture[21-22]. For this study, these effects were minimized by cutting the cruciform specimens from the center of the roll.

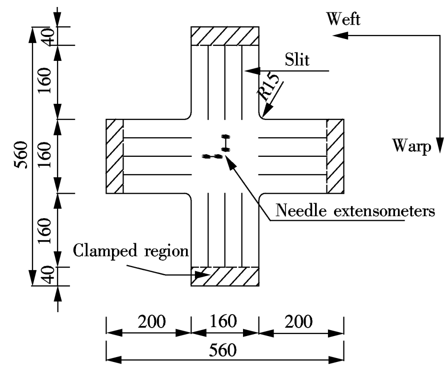

Fig. 3 Cruciform specimen for tests (unit: mm)

1.2 Test setup

Cruciform specimens of the envelope fabric were tested on a biaxial testing machine equipped with two orthogonal independent loading axes (see Fig. 4). This biaxial test equipment used was designed and made by our Research Center of Spatial Structures. Hydraulic power and series of valves, which provide power for the tester, are parametrically controlled to apply any loading spectrum.

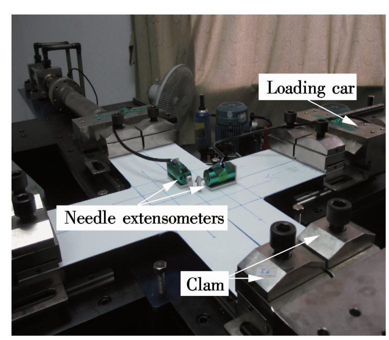

Fig. 4 Biaxial testing machine

Each cruciform arm was loaded independently by two clamps mounted on a loading car. The loading car of each arm was equipped with a load cell of 100 kN to measure the load applied to the specimen. The strains were measured by the use of two needle extensometers placed in the warp and weft direction and bolted onto the test specimen using small diameter screws. The strain gage length was set to be 28 mm.

1.3 Test procedure

Due to the temperature-dependent behavior of the coated fabrics, all tests were carried out at an ambient temperature of (20 ± 2) ℃. In this article, biaxial tests were not intended for strength measurement. They were used to study the stress-strain behaviors and to determine the elastic constants. For this reason, it was only necessary to carry out the tests within a relevant load range, which, therefore, needed to be defined. To the authors' best knowledge, the standard of the Membrane Structures Association of Japan (MSAJ)[13] is the only existing and widely accepted standard for the biaxial testing of coated fabrics[15]. This standard allows some flexibility for sample geometry and test conditions, so that it is applicable to most biaxial machines. The maximum test load was set to be 25% of the ultimate tensile strength (UTS) which was already determined by the mean value of the breaking strengths of the warp and weft specimens under mono-uniaxial loading.

According to the standard of the MSAJ, the load is required to reach zero between every load cycle; namely, there is no pre-stress. However, this condition may be not reasonable for the following reasons: First, an airship structure, despite residual strain of the fabric, must be designed such that a significant level of pre-stress is maintained for the life of the structure to avoid slackness, flapping and probably failure. Then, in order to avoid high initial levels of creep and limit the influence of the recent load history in the test protocol, starting from and returning to a nonzero pre-stress are appropriate. Additionally, the condition of unloading to zero between every load cycle may be not possible to achieve with some biaxial machines[15].

The biaxial test protocol for this study was modified from that of the MSAJ standard. As shown in Fig. 5, the load profile explores various stress ratios with repeated load cycles and a nonzero pre-stress which appeared in a pre-stressing stage (30 min) and at every change of stress ratios. This nonzero pre-stress was set to be 2. 5 kN/m which is higher than that of the standard of the MSAJ, in which it is set be 0 kN/m. For each stress ratio, namely 1∶1, 1∶2, 2∶1, 0∶1 and 1∶0, three cycles must be applied, and at least 3 specimens must be tested.

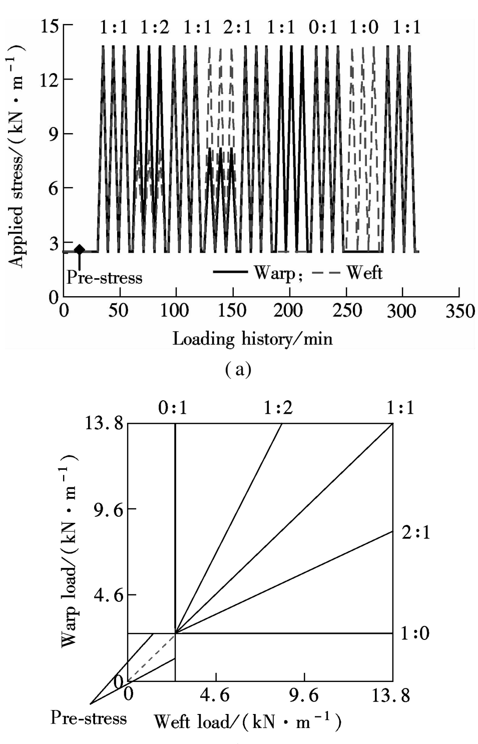

Fig. 5 Biaxial test protocol. (a) Load history; (b) Population of stress space

2 Results and Discussion

2.1 Tensile behaviors under biaxial loads

Biaxial cyclic tests are used to study the stress-strain behaviors and determine the elastic constants. The relevant stress range is between 2. 5 kN/m and the design strength is approximately a quarter of the UTS. The biaxial cyclic tensile curves of this coated fabric are illustrated in Fig. 6. As shown in Fig. 6, the stress ratios of weft

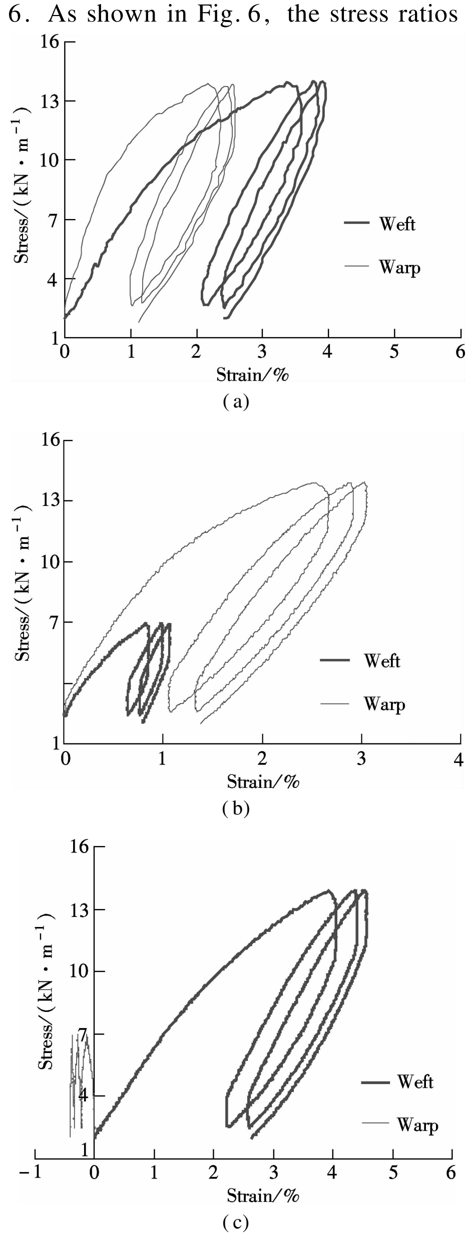

Fig. 6 Stress-strain curves of the coated fabric. (a) 1∶1; (b) 1∶2; (c) 2∶1

stress to warp stress consist of 1∶2, 1∶1 and 2∶1. The stress-strain behavior of the envelope fabric exhibits significant orthotropy. At the same stress level, the weft strain is relatively higher than the warp, and the area of hysteresis cycle in weft is larger than that in warp. With the loading cycle increasing, the nonlinearity of the material response becomes less obvious, and the increment of the lower creep strain (the strain measured when the stress reached its minimum value) between adjacent curves decreases. The lower creep strain after the first cycle is the highest, and after three cycles, the tensile curves are stable and the total creep strain is approximately constant. In unloading curves, due to the viscoelasticity of materials, both the strains in warp and weft increase first and then decrease.

As shown in Fig. 6, in the first cycle, the initial stiffness of the loading direction with higher stress level is large and it decreases at a certain stress level, especially in the warp direction. At the same time, the tensile curves in the direction with the lower stress level are nearly linear. Due to the different levels of the crimp and the looseness in the warp and weft directions of the coated fabric resulting from the production of the woven fabric and the coating process, unbalanced deformations in warp and weft directions occur at different stress ratios. When the stress ratio is 1∶2 (weft: warp), the positive strain occurs in both warp and weft. However, when the stress ratio is 2∶1, the negative strain occurs in warp and positive strain occurs in weft. The state of the shrinkage in the warp direction (negative strain) and the extension in the weft (positive strain) can result in the situation of unbalanced deformations of the structural fabrics[24]. Besides, because of the variations of the elastic moduli in both directions with different stress ratios, the predictability of stress distributions and deformations of structural fabrics will be reduced dramatically. Here, in the design and construction of the fabric structures, the "potential damage" (for example, the shrinkage of the surface) resulting from the special stress distributions should be avoided.

Fig. 7 shows the lower creep strains after each loading cycle in biaxial tests with different stress ratios. To make the figure clearer, each value is the mean value from three specimens since the percent errors are less than 5%. The stress ratio of 10 represents the biaxial test with a stress ratio of 1∶0 (weft∶ warp).

From Fig. 7, it can be noted that during the three loading cycles, when the stress ratio is greater than 1, the lower creep strain in the warp direction is still negative, while in the weft direction the lower creep strain is positive. This phenomenon emphasizes that the stress distribution with stress ratios more than 1 is not recommended in the application of the envelope fabric. Besides, it shows a good elastic recovery of the coated fabrics when

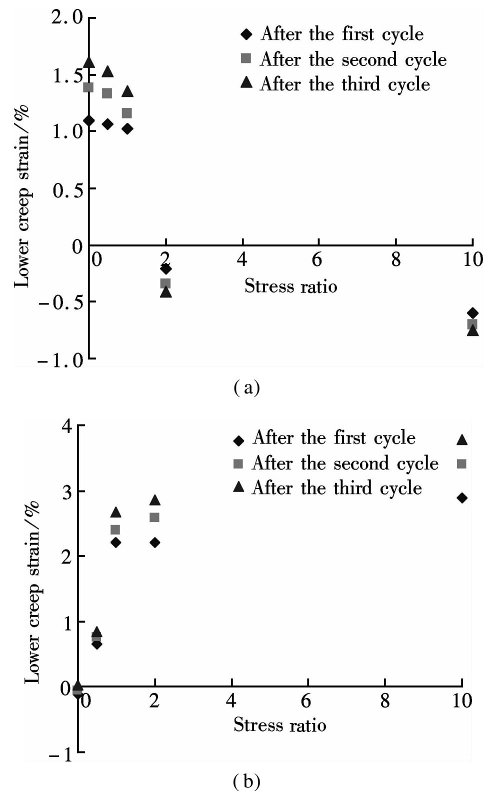

Fig. 7 Lower creep strain after each loading cycle. (a) In warp direction; (b) In weft direction

the load in warp direction is higher than that in weft direction (i. e., the stress ratio is less than 1). When the stress ratio is less than 1, the lower creep strains in both directions are less than 2.0% and the difference after each loading cycle is less than 0.3%. However, when the stress ratio is more than 1, the lower creep strain in weft direction is as great as 3.5% and the difference after each loading cycle is as large as 0.5%, although the lower creep strain in warp direction is still less than 0.3%. The different results of the biaxial tests between a pair of "symmetrical" stress ratios, such as 1:2 and 2:1, should be also attributed to the material orthotropy which results from the inherently unbalanced structure of the coated fabrics[23], in which the crimp of the yarns in weft direction is much higher than that in warp direction. The different lower creep strains between the warp and weft directions can lead to the difference of relaxation in two perpendicular directions, and then can result in difficulty to maintain a stable and smooth surface in airship structures. Therefore, suitable stress ratios should be considered in the design of airship structures to obtain uniform tensile behaviors of coated fabrics. It is also strongly suggested that proper tension should be applied to the weft direction during the coating process to reduce the degree of weft yarn crimp[23].

2.2 Elastic modulus of biaxial tests

In design practice, it is common to approximate the nonlinear warp and weft tensile behavior with elastic constants (two elastic moduli and two Poisson's ratios) to provide values that are compatible with commercially available analysis codes. For this study, the least squares method minimizing the strain terms is used, which minimizes the sum of the squares of the differences between the measured strains and strains calculated for each stress state applied during the tests:

$$S = \sum \left\{ \left[\varepsilon_x - \left(\frac{N_x}{E_x} - \frac{v_{xy} N_y}{E_y} \right) \right]^2 + \left[\varepsilon_y - \left(\frac{N_y}{E_y} - \frac{v_{yx} N_x}{E_x} \right) \right]^2 \right\} \quad (1)$$

where ε is the strain; N is the stress; E is the elastic modulus; and v is the Poisson's ratio; v_{xy} is the transverse strain in the weft (x) direction caused by a stress in warp (y) direction; and v_{yx} is the transverse strain in the warp direction caused by a stress in weft direction. The values of stress and elastic moduli are given per length and not per area. For a linear elastic isotropic material subjected to biaxial stress, the four elastic constants are not all independent; and they are constrained by the reciprocal relationship:

$$\frac{v_{xy}}{E_y} = \frac{v_{yx}}{E_x} \quad (2)$$

The MSAJ standard applies this constraint to the calculation of elastic constants. Bridgens et al. [22] have previously suggested that this constraint is not appropriate for a complex composite material with highly nonlinear stress-strain behavior. The reciprocal relationship is correct in the context of a homogeneous material. A fundamental fact for this research is that coated woven fabrics are not homogeneous materials. The interaction of warp and weft yarns and the behavior of the twisted yarn structure mean that they are better described as a mechanism. It is this mechanical interaction which causes the elastic moduli and Poisson's ratios not to fulfill the relationship for a homogeneous material (see Eq. (2)). Also, this effect is augmented by the fact that the fabric is composed of two different materials. The mechanical properties of the yarns and the coating dominate the fabric response at different load levels (essentially the coating at low load, yarn at high load). In this study, elastic constants have been determined with and without this constraint to investigate its significance for elastic constants values.

Tab. 1 shows the calculated elastic constants using nine variously defined "determination options". The first four determination options make use of all five stress ratios recommended by the MSAJ standard. The calculation method of eight stress-strain paths (i. e. omitting the zero-stress-paths) was recommended in the commentary of the MSAJ standard, and the method of all ten stress-strain paths was proposed by Bridgens et al[22]. Both of the two methods were used to calculate the values of the elastic constants. Additionally, a differentiation was made in regard to constraining the elastic constants by the reciprocal relationship (yes or no); see options 1, 2 versus options 3, 4.

Tab. 1 Elastic constants for the biaxial tests

	Determination options	Analysis type	Elastic moduli/(kN · m^{-1})		Poisson's ratios		Note
			E_x	E_y	v_{xy}	v_{yx}	
1	All stress ratios(8 load-strain paths)	U	342.2 ±6.2	538.9 ±6.5	0.52 ±0.05	0.55 ±0.10	MSAJ modified
2	All stress ratios(10 load-strain paths)	U	275.8 ±9.2	453.1 ±7.2	0.72 ±0.08	0.61 ±0.07	MSAJ modified by Bridgens and Gosling[22]
3	All stress ratios(8 load-strain paths)	C	360.1 ±4.8	515.2 ±5.4	0.66 ±0.07	0.45 ±0.12	MSAJ original
4	All stress ratios(10 load-strain paths)	C	291.1 ±7.3	431.2 ±9.1	0.81 ±0.09	0.54 ±0.02	MSAJ modified
5	Two stress ratios(1∶1/0∶1)	U	244.8 ±5.0	601.7 ±5.1	0.54 ±0.02	0.40 ±0.05	Effect analysis of stress ratio
6	Two stress ratios(1∶1/1∶2)	U	348.7 ±4.3	537.8 ±5.1	0.64 ±0.13	0.48 ±0.08	
7	Two stress ratios(1∶1/2∶1)	U	434.2 ±4.9	466.1 ±2.9	0.57 ±0.11	0.50 ±0.05	
8	Two stress ratios(1∶1/1∶0)	U	485.9 ±5.1	401.6 ±3.8	0.67 ±0.09	0.43 ±0.04	
9	Average of (options 6 and 7)	U	391.5 ±4.6	502.0 ±4.0	0.61 ±0.12	0.49 ±0.04	

Notes: U represents unconstrained elastic constants (i. e. four independent values); C means constrained, elastic constants calculated to satisfy the reciprocal relationship.

The rest of the determination options 5 to 8 in Tab. 1, have been defined by the authors to study the influence of different stress ratios on the elastic constants of the coated fabric. In all 4 options, the determination was conducted using the stress ratio 1∶1, combined with any one of the other four stress ratios, namely 0∶1, 1∶2, 2∶1 and 1∶0 (at least four stress-strain-paths are needed for the determination of the unknowns). Using the same stress ratio 1∶1 is appropriate because, despite the diversity of loading conditions, structures are often designed such that almost identical membrane forces in warp and weft directions are developed to bring the good performances of fabrics into full play. As mentioned earlier, the elastic moduli and Poisson's ratios do not obey the reciprocal relationship. For these four determination options, elastic constants have been determined without the constraint of the reciprocal relationship. For an airship structure with stress ratios (weft: warp) mainly varying between 1/2 and 2/1 under design loading, the stress ratios 1∶2 &1∶1 (option 6) and 2∶1 & 1∶1 (option 7) might be both reasonable;

therefore, an average method was adopted to calculate the elastic constants (option 9).

According to Tab. 1, using the determination options based on the commentary of the MSAJ (options 1 to 4) results in a great variety of values for the calculated elastic constants: E_x varies between 275.8 and 360.1 kN/m; E_y between 431.2 and 538.9 kN/m; v_{xy} between 0.52 and 0.81; and v_{yx} between 0.45 and 0.61. The zero-stress-paths were taken into account, because they contain relevant mechanical information regarding the load bearing behavior of anticlastic structures. Comparing options 1 and 3 with options 2 and 4, it can be found that the calculated stiffness E_x and E_y decreases dramatically when the zero-stress-paths are taken into account.

A comparison of the determination options 1 and 3 shows that applying the reciprocal relationship has a significant influence on the calculated constants if only eight stress-strain-paths are evaluated, especially on Poisson's ratios. Applying the reciprocal relationship can increase the values of v_{xy} and decrease those of v_{yx}, e. g. from 0.52 to 0.66 and from 0.55 to 0.45, respectively. The influence of the reciprocal relationship is smaller if ten stress-strain-paths are evaluated, as can be seen from the results for determination options 2 and 4: Poisson's ratio v_{xy} increases from 0.72 to 0.81 and v_{yx} decreases from 0.61 to 0.54.

If a two-stress-ratio method is used for the determination of the elastic constants, the results vary even more (see determination options 5 to 8 in Tab. 1). Especially, the stiffness values reach extreme values: E_x varies from 244.8 up to 485.9 kN/m and E_y varies from 401.6 up to 601.7 kN/m. The average method (option 9) is appropriate for the airship structures for the characteristics of the membrane stresses of the envelope fabrics. The evaluation values of elastic constants using option 6 and option 7 were averaged to determine those values of coated fabrics for airship structures.

It appears that the values of elastic constants evaluated from one biaxial test depend significantly on the underlying determination options, even if, as performed in the present investigations, only one numerical correlation method is applied, and if the calculated values are optimized only for one load range. In real design practice, it might be more reasonable to use elastic constants which are determined for specific load ranges and stress ratios depending on the project's needs. Also, concerning design practice, it is also recommendable in light of the great variety of the constants' values to calculate fabric structures with two limitative sets of elastic constants instead of using only one single set. If the variability is not so pronounced, then an average of both limits is recommended for the material constants.

The definition of the stress ratios is of common use and denotes the ratio of the weft stress to warp stress. We use the normalized stress ratios in weft and warp direction which were proposed by Galliot and Luchsinger[16]. The normalized stress ratios are defined as

$$\gamma_x = \frac{N_x}{\sqrt{N_x^2 + N_y^2}} \tag{3}$$

$$\gamma_y = \frac{N_y}{\sqrt{N_x^2 + N_y^2}} \tag{4}$$

The elastic constants obtained from the experiments (corresponding to options 5 to 8 in Tab. 1) are detailed in Fig. 8, where the elastic constants (two elastic moduli and two Poisson's ratios) are plotted as a function of γ_x. The results show that the elastic moduli noticeably vary with the normalized stress ratios. A higher stress ratio in one direction contributes to a higher elastic modulus in that direction and a lower elastic modulus in the orthogonal direction. This strong interaction between warp and weft direction is the result of the crimp interchange (see Fig. 2). The yarn waviness relies on the weave geometry as well as on the stress ratios. At the crossover points of the yarns, the contact forces balance the loads which are applied to the yarn directions. Consequently, increasing the stress in one direction straightens the yarns in that direction while it aggravates the waviness of the orthogonal yarns. Furthermore, the yarn waviness directly affects the elastic moduli of woven fabrics. The elastic modulus of one direction increases with the decrease of the yarn waviness of the same direction. As a result, the highest value

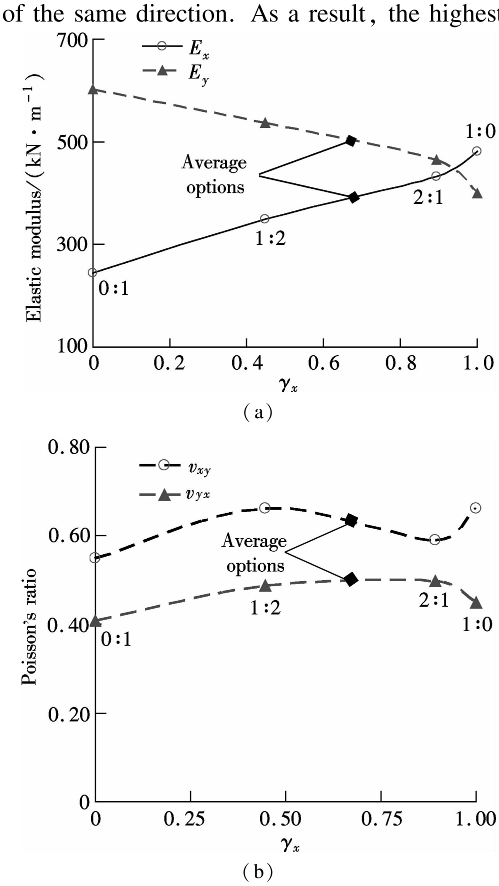

Fig. 8 Influence of the normalized stress ratios. (a) Elastic modulus; (b) Poisson's ratios

of E_y is obtained for a 0∶1 ratio, and the highest value of E_x for a 1∶0 ratio.

Fig. 8 also indicates that the elastic modulus in the warp direction is higher than that in the weft direction, which is a common phenomenon. The warp yarns are often pre-tensioned during the material manufacturing process; therefore, the initial waviness of the warp yarns is much lower than that of the weft yarns. Another characteristic of the curves in Fig. 8 is that the elastic moduli are almost linear functions of the normalized stress ratios, whereas the Poisson's ratios are virtually independent of the stress ratios. This observation can be used to modify the material models integrated into the commercial finite element soft wares. Indeed, according to the plane stress theory, Poisson's ratios cannot exceed 0.5. However, most of the values of Poisson's ratios detailed in Tab. 1 exceed 0.5, which is the result of high level of warp-weft interaction and large negative strains to some extent.

Inspections of the values of elastic modulus and Poisson's ratio (options 5 to 9) in Tab. 1 show that these values adhere more closely to an inverse of the reciprocal relationship for this coated fabric with different stress ratios. Here, a coefficient K is introduced for the relationship to hold:

$$\frac{v_{xy}}{E_y} = K \frac{v_{yx}}{E_x} \tag{5}$$

The values of K are visible in Fig. 9 for options 5 to 9 in Tab. 1, and the value of 1.0 is the coefficient K for the materials satisfying the reciprocal relationship. As illustrated in Fig. 9, the value of coefficient K significantly changes with the stress ratios. Consequently, the relationship between stress and strain of this material is influenced by the stress ratios. Besides, a larger difference of stress between the two directions results in a greater difference between the value of coefficient K and the value of 1.0. When the stress ratios are close to 1∶1, the value of K is approximately 1.0, which suggests that the reciprocal relationship (see Eq. (2)) likely applies to the coated fabrics with uniform stress distribution. For the airship structures, as the stress ratio of the two directions mainly changes from 1/2 to 2/1, the authors suggest applying the reciprocal relationship to the calculation of elastic constants for airship structures to simplify the computation.

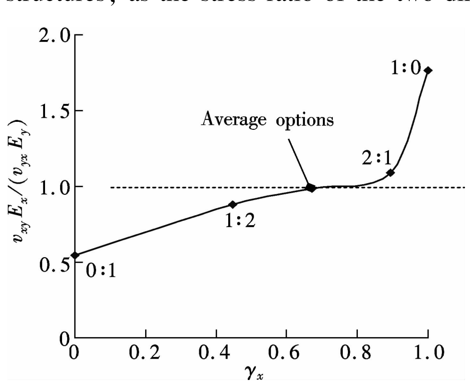

Fig. 9 Influence of the normalized stress ratios on the coefficient of reciprocal relationship

3 Conclusion

For the stress-strain behaviors, the studied material exhibits a significant orthotropy and nonlinearity. The orthotropy of the material originates from the different levels of the crimp and the looseness of yarns in two directions. Due to the unavoidable imbalance in yarn crimp, suitable stress ratios should be determined to maintain a stable and smooth surface in fabric structures. For the elastic constants, a great variety in the elastic constants can be obtained for this coated fabric, depending only on the different determination options. The elastic moduli of biaxial tests noticeably vary with the normalized stress ratios. A higher stress ratio in one direction probably contributes to a higher elastic modulus in that direction and a lower elastic modulus in the orthogonal direction. In real design practice it is more reasonable to use elastic constants which are designed for specific load ranges and stress ratios depending on the project's needs.

Although this research is concerned with one type of coated fabric, the results are also applicable to other coated fabrics for airship envelopes using the same woven technology to some extent. To fully verify the results, future work will include more experimental data for other types of coated woven fabrics.

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飞艇蒙皮材料双轴拉伸力学性能和弹性常数计算

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摘要：以蒙皮材料 Uretek3216L 为对象开展了膜材的双轴循环拉伸力学性能试验研究. 首先，通过一系列双轴循环试验获得了膜材的应力应变数据，并对其非线性、各向异性等性质进行了探讨分析. 然后，运用应变残差最小二乘法，计算出不同应力比组合的弹性常数. 最后，分析了应力比的组合方法及正交互补性质对膜材弹性常数的影响规律. 结果表明，经纬向纱线卷曲形态的不均衡性是膜材正交异性特征的主要原因. 膜材的弹性常数受应力比组合方法及正交互补性质的影响显著，且弹性模量随名义应力比的改变而有规律地变化. 在结构设计中，需要根据具体受力状态及应力比范围来确定膜材的弹性常数，以提高设计分析的精确性；且考虑到弹性常数的多变性，采用 2 组界限弹性常数比仅采用 1 组更可取.

关键词：涂层织物；飞艇；拉伸性能；正交互补性质；弹性常数；应力比

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