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Finite element simulation of pressing fabric switch at low speed

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The partial weave of a through-interlocking fabric switch has been simplified, and the 1/3 twill woven fabric model is set up. Finite element software Workbench has been used to simulate the dynamic response of 1/3 twill woven fabric compressed at a low speed by a sphere and to analyse the compressive deformation process of the 1/3 twill woven fabric. The influence of yarn material properties, the friction coefficient among yarns at crossovers, the friction coefficient between sphere and fabric, and the compression traverse of sphere on the compressibility of through-interlocking fabric switch are studied. The results reveal that the pressing pressure of the fabric switch increases with the increase in elastic modulus of insulating yarns, the friction coefficient among the yarns at crossovers, the friction coefficient between sphere and fabric, and the height of supporting part.

Keywords: 1/3 twill woven fabric, Compressibility, Finite element method, Through-interlocking fabric switch, Workbench

1 Introduction

A through-interlocking fabric switch is a kind of smart textile. Conductive wire is woven into the fabric via a three-dimensional (3D) weaving method. The fabric switch can achieve the function of an electronic switch due to its special hollow structure. In the future, fabric switches will not only be woven into sleeves for playing music, making a call and inputting information, but could also be used for domestic functions such as controlling illumination, household appliances, etc. Therefore, the prospect has wide application.

With the development of computer technology, numerical simulation method exhibits powerful functions. The mechanical properties of fabric are simulated and analysed with the help of a finite element analysis tool, which has developed a common method for studying fabric mechanics. Duan *et al.*[1-4] and Rao *et al.*[5,6] studied the influence of mechanical properties, friction coefficient and boundary conditions of the yarn on the energy absorption of fabrics using the finite element analysis method. Chocron *et al.*[7] modelled full-scale fabric system and simulated the impact behaviour of the single layer and multiple layers by LS-DYNA. Wang *et al.*[8] stated the tear damage of different kinds of woven fabric from finite element analysis and experiments. It was found that the tearing strength is closely connected with the friction among yarns, the fabric structure and the weaving density. Additionally, Jia *et al.*[9] studied the failure mechanisms of 3D orthogonal woven fabric under ballistic impact using the commercial finite element software ABAQUS. Wang *et al.*[10] investigated the stab damage behaviours of uncoated and coated woven fabric from finite element methods and experimental. The results revealed that the stab resistance of coated woven fabric was better than that of the uncoated woven fabric. Using finite element analysis, Cao *et al.*[11] studied the influence of pile density, pile height, Young's modulus and Poisson ratio of the 3D hollow integrated sandwich composites on the compressive properties.

Compressibility is the most important mechanical property in using the fabric switch process, and compression mainly occurs in the orifice part. The upper and lower layers come into contact with each other when the upper layer of the orifice part is subjected to compressive loads, so completing the circuit of the fabric switch. In this study, twill weaves in the upper layer of orifice part in the through-interlocking fabric switch are modelled, and the compressibility of 1/3 twill woven fabric is the main area of study. To a certain extent, the compressibility of 1/3 twill woven fabric can represent a fabric switch. Referring to the simulation method of fabrics under ballistic impact, textile structural composites subjected to high velocity impact are adopted and

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their impact response and damage mechanism are studied. In this study, textile structural composites under ballistic impact are modified as the fabric is compressed at a low speed by a sphere simulating the effect of a fabric switch pressed by a finger. A finite element analysis model is created using Workbench to simulate the process and analyse the deformation condition of the fabric subjected to compressive loads. The influence of the yarn material properties, the friction coefficient among the yarns, the friction coefficient between sphere and fabric and the compression traverse of sphere on the compressibility of through-interlocking fabric switch are studied to further optimize the performance of the fabric switch.

2 Materials and Methods

2.1 Structure

Figure 1 shows the fabric structure of through-interlocking fabric switch. The through-interlocking fabric switch is made up of polyester staple yarns of 59 tex fineness. The angle-interlock structure with interwoven warp and weft yarns is adopted for the support part. The weaving of a support part with the angle-interlock structure is continued by the weaving of an orifice part. The circled numbers from 1 to 62 represent the total of 62 weft yarns. The numbers from 1 to 6 represent the six layers of warp yarn in the first part, while the numbers from 7 to 12 show the six layers of warp yarn in the second part. The weft yarns from number 1 to 35 are the support part of the fabric switch, and the upper and lower layers of the orifice part are separated by the middle two layers of weft yarn. Every layer of warp yarn is interwoven in the whole fabric, which connects the fabric as a whole. The weft yarns from number 36 to 62 are the orifice part.

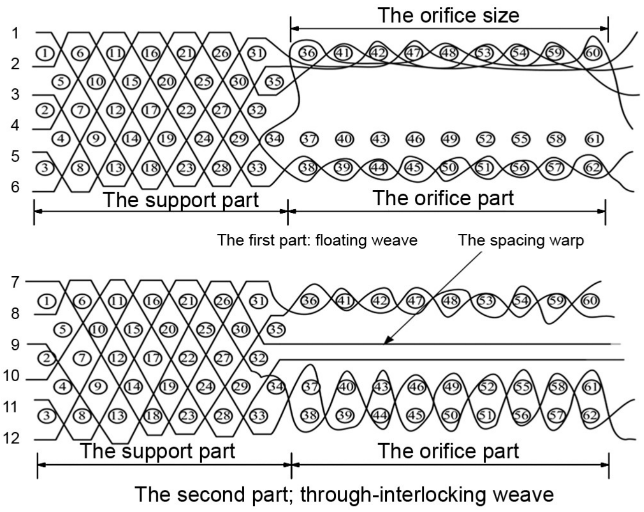

Fig. 1 — Warp cross-section drawing of through-interlocking fabric

2.2 Simplification

A through-interlocking fabric switch is woven using a number of yarns. The yarns are assembled together based on the weave structure, so drawing the model of the through-interlocking fabric switch is extremely complex. Many elements are generated in finite element meshing and there are a number of contacts among the yarns, and between the sphere and the fabric, which lead to increased demand for computational performance and a significant rise in calculation time. In addition, the experimental scheme is bad for improvement. Considering these reasons, 1/3 twill weaves in the upper layer of the orifice part are modelled and reported in this paper. On the basis of twill weaves, the pressing process of the fabrics is simulated using Workbench.

2.3 Test Methods

2.3.1 Tensile Tests

In order to endow the actual yarn with the material properties and improve the accuracy of the simulation results in finite element modelling, a sample of 10 polyester staple yarns (30 cm long) was tested along their lengths using a universal material testing machine to obtain the yarns material properties. The distance between the upper and the lower chuck was taken as 20 cm. Tensile tests were carried out 10 times at a tensile speed of 50 mm/min. Calculations were made to obtain a list of tensile parameters for the yarns 10 using the following equations:

$$E = \frac{\sigma_0}{\varepsilon_0} \qquad \ldots (1)$$

$$\varepsilon_0^{pl} = \varepsilon_f - \varepsilon_0 \qquad \ldots (2)$$

The tensile parameters of polyester yarns are: 105 E (MPa), 16.5 σ_0 (MPa), 19.5 σ_f (MPa) and 0.2 ε_0^{pl}.

2.3.2 Pressing Tests

The pressing pressure of fabric switch was tested by LLY-06 fabric keyboard loading instrument. The test indenter, with a diameter of 5 mm, was placed in the centre of target key in the orifice part, and has a pressing speed of 240 mm/min along the vertical direction. The upper and lower layers of the orifice part come into contact with each other when the target key is subjected to pressing loads, so completing the circuit of the fabric switch, and the pressing pressure of fabric switch was obtained.

2.4 Finite Element Modelling

2.4.1 Material Parameters

The density of polyester staple yarns was taken as 1.38 g/cm^3 and the isotropic constitutive model[12] was used for yarn model. The longitudinal elastic modulus obtained from tensile tests and Poisson's ratio was 0.3. In the process of compressing the fabric, the yarns cannot be broken, so there is no need to define the failure parameter of the yarns. The sphere is defined as a rigid body. The material parameters of the yarn and the sphere are listed in Table 1.

2.4.2 Contact

Surface-to-surface contact with a friction coefficient of 0.2 was used for the interaction among the yarns at the crossovers, and between the sphere and the fabrics.

2.4.3 Mesh Scheme and Boundary Conditions

The 1/3 twill woven fabric consists of 8 warp and weft yarns respectively. The sphere, with a diameter of 4 mm, is located in the centre of the fabric, and only has a negative compression speed of 240 mm/min along the y-direction. All degrees of freedom at the edges of the warp and weft yarns are constrained. The yarns are meshed with hexahedral elements. The yarns are meshed into eighty elements along the yarn's length, six elements along the width and two elements through the thickness. There are 15360 elements and 95568 nodal points for the 1/3 twill woven fabric. For the sphere, the element size is 0.3 mm. Its mesh method is MultiZone and it has 1320 elements and 6433 nodal points.

3 Results and Discussion

3.1 Deformation of 1/3 Twill Woven Fabric

In the process of compressing fabrics, the compression speed of the sphere is 240 mm/min, the compression traverse is 2 mm, and the end time of the dynamics analysis settings is 0.5 s. Figure 2 shows the compressive deformation of 1/3 twill woven fabric.

It can be seen from Fig. 2 that the deformation of fabrics continuously spreads from the centre out to the periphery, presenting a rectangular pyramid back bulge that increasingly expands. When the computing time is 0.22 s, the sphere makes contact with the fabrics, after which the yarn crimp around the sphere gradually disappears and becomes straight under the compression of the sphere. When straight, yarns stretch and deform to further overcome the compression of the sphere. At the ends where the warp and weft yarns are fixed, the stress value inside the compressed yarns increases, thus small bump is formed at the back of the fabric. When the computing time is at 0.41 s, the sphere further compresses the fabric, thus the yarns in contact with the sphere are pushed around. The uncompressed yarns move towards the thick area and the centre due to the friction between warp and weft yarns at the crossovers, so that rectangular pyramid areas are formed at the back of fabric. When the computing time is at 0.5 s, the sphere continues to compress the fabric; as a result, the deformation of the uncompressed yarns becomes greater. The stress values inside the compressed yarns increase, and the compressed rectangular pyramid area attains its maximum.

Table 1 — Material properties of FE model

Model	Density g/cm^3	Young's modulus Pa	Poisson's ratio
Yarns	1.38	1.05E8	0.3
Sphere	8.93	2.07E11	0.32

3.2 Comparison of Pressing Pressure between Simulation and Experimental

The accuracy of finite element modelling has been validated by comparing with experimental results, as shown in Fig. 3.

There are good agreements between simulation and experimental results. It can be seen from the figure that the pressing pressure of fabric switch increases with the rise in displacement. For the displacement between 0 mm and 1.8 mm, the pressure value from finite element modelling is a little more than that of the experimental value. This is the main reason that the degrees of freedom at the edges of warp and weft yarns are fully constrained and the yarns are considered to be solid model during the simulation process. The fibre gap and fibre slippage are neglected. For the displacement between 1.8 mm and 2 mm, the simulation value is closed to the experimental value. This is due to the reason that during the experiment, there is 0.3 s compressing time when the indenter attains the position of 2 mm. At that time, the fabric is subject to the acting force of immovable indenter, and the reaction force of fabric on the indenter increases due to resilience of yarns, which results in the considerable increase of experimental curve, when the indenter is close to rated displacement.

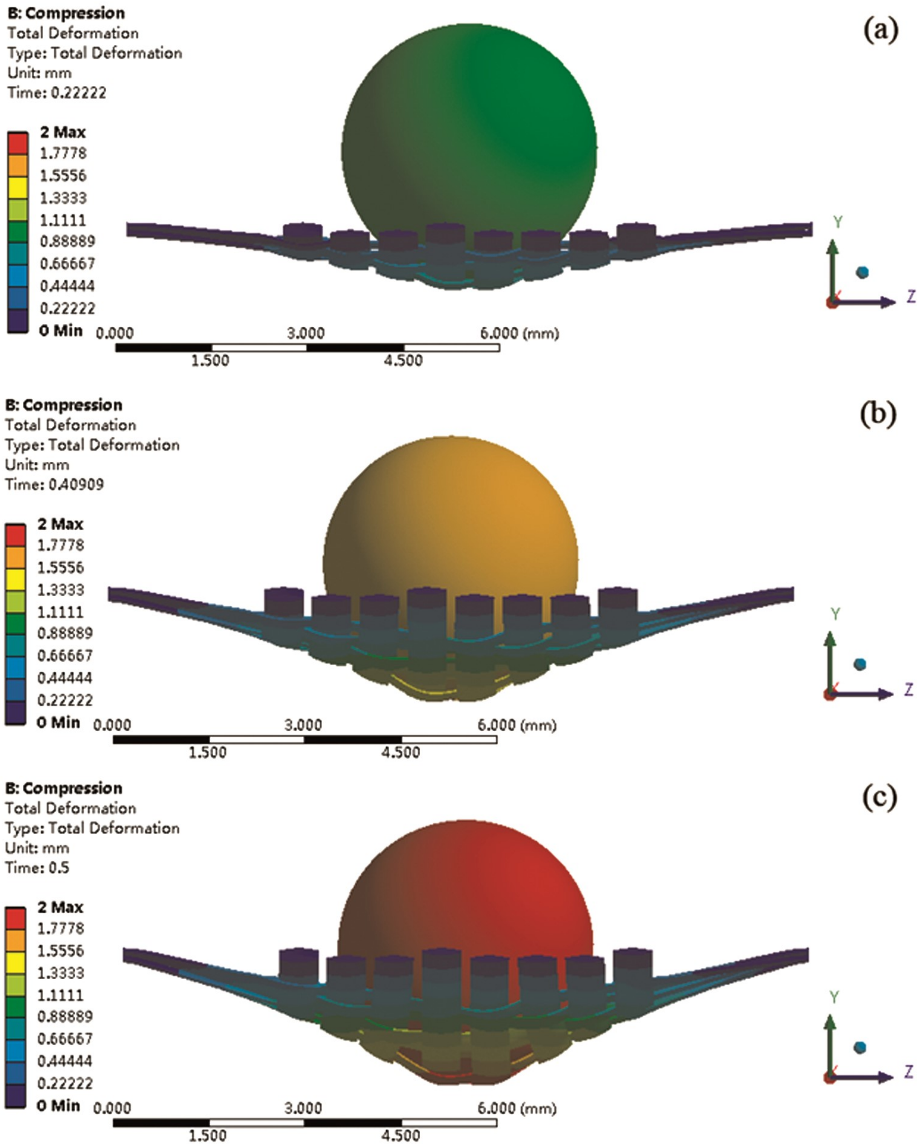

Fig. 2 — Compressive deformation of 1/3 twill woven fabric at different instants of time (a) 0.22 s , (b) 0.41 s, and (c) 0.5 s

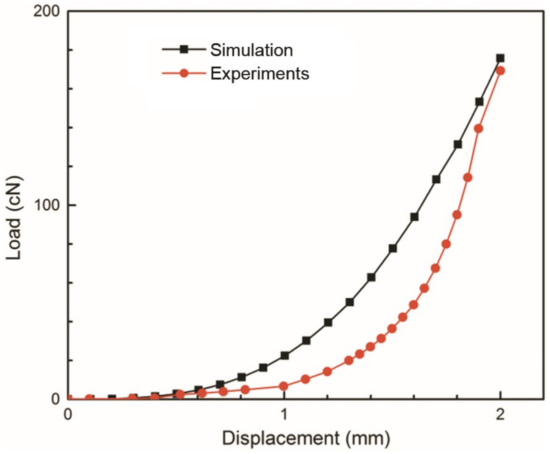

Fig. 3 — Contrast curve of load-displacement between simulation and experiments

3.3 Influence of Material Properties on Compressibility of Fabric Switch

The influence of material properties on the compressibility of the fabric switch is studied by changing the properties of insulating material in the fabric switch, which is based on the modification of material properties of the yarns. Considering the same compression speed, two kinds of materials are set up, viz Material 1 and Material 2. Material 1 has the same material properties as polyester yarns (Table 1), while Material 2 has an elastic modulus three times larger than that of the yarns from Material 1. Figure 4(a) shows the load-displacement curve for different materials.

It can be seen from Fig. 4(a) that in the enlarging process of the compression traverse, the pressing

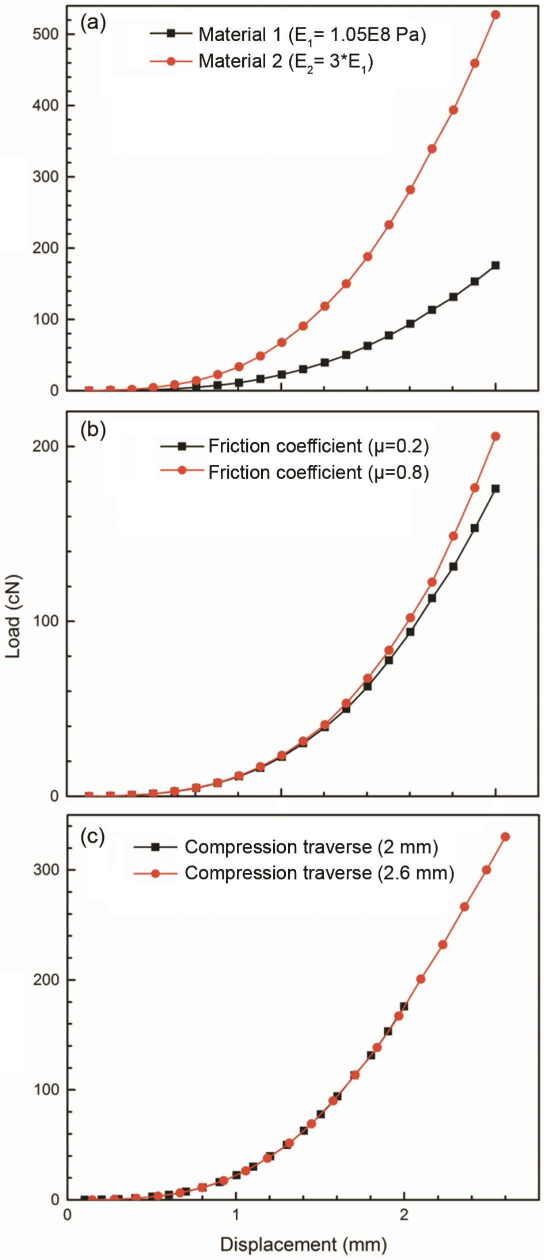

Fig. 4 — Contrast curve of load-displacement with (a) different material properties, (b) different friction coefficients and (c) different compression traverses

pressure of Material 1 and 2 also grows. The pressing pressure of Material 2 is approximately three times higher than that of Material 1. The elastic modulus of Material 2 has a more evident impact on the compressibility of the fabric switch. With the rise in elastic modulus, fabric rigidity increases, making deformation more difficult. Therefore, to achieve the same compression traverse, more compressive load needs to be applied to the fabric to increase the pressing pressure. Thus, it can be concluded that the pressing pressure of the fabric switch increases with the rise in elastic modulus of insulating yarns.

3.4 Influence of Friction Coefficient on Compressibility of Fabric Switch

With the same material properties, two values of friction coefficient are taken namely μ=0.2, μ=0.8. Figure 4(b) shows the contrasting load-displacement curves with different friction coefficients.

It can be seen from the figure that, with the increase in compression traverse, the pressing pressure of the fabric with the friction coefficient of μ=0.8 is always greater than that of the fabric whose friction coefficient is μ=0.2. This is due to the friction between the sphere and the fabric and among the yarns. The increase in friction coefficient could increase the resistance between the sphere and the fabric, thus the slippage between the warp and the weft yarns at the crossovers becomes harder, and the pressing pressure of the fabrics increases. As a result, the pressing pressure of the fabric switch rises with the increase in friction coefficient among the yarns and the friction coefficient between the sphere and the yarns.

3.5 Influence of Compression Traverse on Compressibility of Fabric Switch

The compressibility of fabric switch is influenced by the height of support and is studied by changing the compression traverse of the sphere. With the same material property, compression speed and friction coefficient, the compression traverse is enlarged to 2.6 mm, the compression speed of the sphere remains the same, and the time to reach the set compression traverse is 0.65 s. Figure 4(c) shows the load-displacement curves with different rates of compression traverse.

It can be seen from the figure that, when the compression traverse is 2.6 mm, the final pressing pressure of the fabric is greater than that in the 2 mm compression traverse. With increased compression traverse, the support part of the fabric switch is higher. As a result, the embedding position of the sphere into the fabric is larger. With the greater distance travelled by the sphere, the fabric has greater deformation in the process of impeding sphere movement, and the pressing pressure of the fabric increases. Therefore, the pressing pressure of the fabric switch is greater with the increase in the height of the support part.

4 Conclusion

This paper presents the compression simulation of 1/3 twill woven fabric by the finite elements software

Workbench. The simulation results are compared and show a good agreements with the experimental results. Through the control of the material properties of the yarns, the friction coefficients among the yarns and between sphere and fabric, and the compression traverse of the sphere, the load-displacement curve has been analysed. It is concluded that the three factors greatly affect the compressibility of the through-interlocking fabric switch. The pressing pressure of the fabric switch increases with the rise in the elastic modulus of insulating yarns. The pressing pressure of the fabric switch rises with the increase in the friction coefficient among the yarns and the friction coefficient between sphere and yarns. The pressing pressure of the fabric switch is greater with the increase in height of support part.

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