EFFECT OF FABRIC SURFACE'S CLEANLINESS ON ITS MOISTURE/AIR PERMEABILITY

by

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A fabric's moisture/air permeability is a main factor for the fabric design for advanced applications, and no theoretical model was available in literature for an optimal permeability. In this paper, we use the capillary-like effect to elucidate the permeability property, and the effect of nano/micro particles on the fabric's surface on the permeability is studied by the geometric potential theory. Our theoretical analysis shows that an unclean surface gives a negative impact on the permeability. A superhydrophobic surface is needed to design a good and lasting moisture/air permeability.

Keywords*: Capillary-like force, boundary-induced force, geometric potential, surface energy, surface tension, nanofibers, hierarchical pores, coating, sportswear, cocoon*

Introduction

The moisture/air permeability of a fabric plays an important role in the modern fabric design for various advanced applications [1-4], *e.g.*, sportswear. Good moisture permeability has an effective antibacterial property and a dust-free property and a fast sweat diffusion. Good air permeability has an excellent comfort, and it is required for a bandage. Cocoons have the best moisture/air permeability in all nature materials, and have been extremely studied for designing bioinspired structure fabrics [5-10]. It has been proved experimentally that cocoons' pores' hierarchical structure affects greatly the permeability, the phenomenon can be explained theoretically by the geometric potential theory [11-13]. Any a boundary can produce surface energy or surface tension, or geometric potential. The boundary-induced potential can be expressed:

$$\Pi \propto \frac{1}{r^n} \tag{1}$$

where Π is the geometric potential, r – the surface's curvature radius, and n – the index. For spherical shape, $n = 1$.

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The boundary-induced force is:

$$F = -\frac{\partial \Pi}{\partial r} \tag{2}$$

The geometric potential theory was successfully applied to explain the mechanism of Fangzhu's water collection property [14-16], the fiber's morphology [17], smart adhesion [18, 19], and cell orientation [20]. In this paper we will apply the geometric potential theory to explain the moisture/air permeability of a fabric.

Capillary effect

The capillary effect can be expressed [21-24]:

$$h = \frac{2\sigma\cos\theta}{\rho g r} \tag{3}$$

where h is the capillary rise in a capillary tube, σ – the surface tension, θ – the contact angle, ρ – the fluid's density, g – the acceleration of gravity, and r – the radius of the capillary tube.

Equation (3) is valid for cylindrical tubes. For an arbitrary shape, we can apply the geometric potential theory to study the capillary-like effect.

In this paper we assume that the pores in a fabric can produced a capillary effect like geometric potential, see fig. 1.

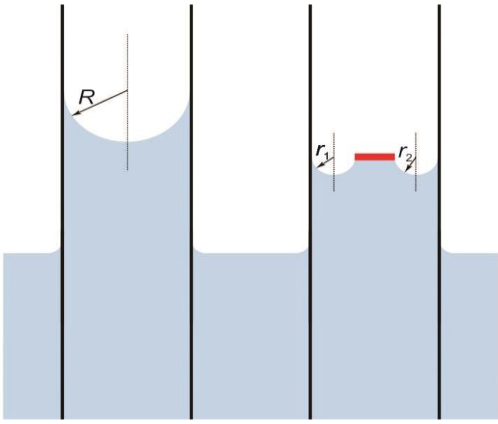

Figure 1. The capillary effect of a small tube and the geometric potential for a non-cylindrical boundary

For simplicity we assume the crescent shape is a hemispherical surface, and assume the vertical force per area produced by the crescent shape is f, then the force balance requires:

$$\pi R^2 f = \rho g h \tag{4}$$

where R is the tube radius and h is the capillary rise.

According to eq. (3), we have:

$$f = \frac{\rho g h}{\pi R^2} = \frac{2\sigma\cos\theta}{\pi R^3} = \frac{k}{R^3} \tag{5}$$

where k is a constant for a given pore.

Fabric's porous structure and its moisture/air permeability

The fabric consists of yarns used for warp and weft, and periodic pores are formed. A smaller pore can produce a higher capillary-like force for moisture/air diffusion. The pore's equivalent radius, R, scales with the radius of the yarn, r_{yarn}:

$$R \propto r_{\text{yarn}} \tag{6}$$

Generally the yarn's radius ranges from micro meters to millimetres. In order to have a good permeability, a hierarchical pore structure should be designed by covering several cascades with different pore sizes, *e.g.*, $r_{\text{yarn}}/10$, $r_{\text{yarn}}/100$, and $r_{\text{yarn}}/1000$, until to hundreds of nanometres. Liu, *et al.* [25] revealed that a nanofiber membrane with hierarchical pores has a good air permeability. A fabric's moisture/air permeability can be controlled by covering few cascades with pores ranging from few micrometres to hundred nanometres by electrospinning or the bubble electrospinning [26-30], the designed fabric can be used as a receptor in the spinning process.

Effect of nano/micro particles adhered on the surface on the moisture/air permeability

The fabric's surface cleanliness, especially the nano/micro particles which are adhered on the surface, will greatly affect the moisture/air permeability. Figure 1 shows a particle on a capillary pore, and we assume radii of crescent shape beside the particle are r. According to the geometric potential theory, the total vertical force of the annulus of crescent shape is:

$$F = \pi r(2R - 2r)f = \frac{2\pi kr(R-r)}{r^3} = 2\pi kr^{-2}(R-r) \tag{7}$$

It is obvious that:

$$\frac{\mathrm{d}F}{\mathrm{d}r} = 2\pi k(-2Rr^{-3} + r^{-2}) = \frac{2\pi k(-2R+r)}{r^3} < 0 \tag{8}$$

Equation (8) reveals that F is a monotone decreasing function of r. So the particle in the capillary pore reduces the capillary force, and the moisture/air permeability is decreased.

In order to keep the permeability unchanged during use, a superhydrophobic surface is helpful, a dust-free surface is needed to design a good and lasting moisture/air permeability.

Conclusions

In this paper, we study theoretically the fabric's moisture/air permeability using the geometric potential theory, and conclude that the nano/micro particles, which are adhered on the fabric's surface, give a negative effect on the permeability, and a superhydrophobic surface should be designed for a good and everlasting permeability. The present theory gives a theoretical foundation of an optimal design for a given permeability. The coating technology is widely used for design of a superhydrophobic surface, but it gives a negative impact on permeability. A porous coating film is needed, and its pores form the last cascade of the fabric's pores' hierarchical structure.

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