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The effect of sweat on the performance of the interface between skin and flexible membrane

Weijie Xian[a], Yulan Liu[a,*], Biao Wang[b]

[a] School of Engineering, Sun Yat-sen University, Guangzhou 510275, PR China
[b] School of Physics, Sun Yat-sen University, Guangzhou 510275, PR China

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ABSTRACT

Upon realizing the importance of the sweat in controlling the performance of the interface crack between skin and flexible membrane, the effect of sweat on the crack opening under action of the far-field tensile stress is analysed in present paper. Application of the complex variable method and the principle of superposition gives the crack opening displacement and the stress intensity factors, which are functions of the surface tension, contact angle, location and size of the sweat. The location of sweat has important influence on the stress intensity factors, although it induces very little changes in the shape of the crack opening. Without or with the action of a small far-filed tensile stress, the sweat can induce the crack partial closure. With the increase of the far-field tensile stress, the crack opening displacement will be large enough to cause the disruption of the sweat, even induce the crack growth. So, the far-field tensile stress, which can split the sweat, is derived in present paper.

1. Introduction

In recent years, flexible electronics have attracted much attention due to their biocompatibility, high stretching ability and non-toxicity. Kim et al. [1] proposed an electronic system, incorporating the sensors, wireless power devices, electronic circuits and flexible membranes, matched to the epidermis. At present, the flexible electronics is mainly used in the medical area such as to measure electrical activity produced by brain, heart, skin and so on [2].

The measuring of physiological signals is crucial for medical diagnosis and therapeutics [3,4], so that it requires excellent physical contact between the flexible membrane and the epidermis. However, there may exit pores between flexible membrane and the epidermis in reality, and the sweat may appear in these pores to influence the contact between flexible membrane and epidermis. In modelling, we can regard the sweat as liquid bridges or capillary droplet. So, it's necessary to study the effect of the liquid bridge on the interface between skin and flexible membrane.

Recently, there have been many studies focusing on the local deformation of flexible membrane caused by a capillary droplet [6–8]. Yu and Zhao [9] gave the theoretical solution of the surface deformation of substrates with finite thickness induced by a sessile liquid droplet based on the Lester's assumptions by the virtue of Hankel transformation. Karpitschka et al. [10] analysed the stick-slip motion for viscoelastic capillary dynamics valid beyond droplets. Park et al. [11] proposed that the cusp of the ridge was bent with an asymmetric tip, which were determined by the surface stresses. Yang et al. [12] analysed the effect of a capillary bridge on the crack opening of a penny crack.

In summary, liquid bridges or liquid droplets play an important role in controlling the performance of the flexible membranes.

* Corresponding author.
E-mail address: stslyl@mail.sysu.edu.cn (Y. Liu).

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Nomenclature

a	the crack length
b	the distance from the right bound of sweat bridge to the right tip of crack
c	the distance from the left bound of sweat bridge to the right tip of crack
$c-b$	the wetting area of sweat bridge
$(b+c)/2$	the distance between right tip and the centre of sweat bridge
E_j	Young's modulus ($j = 1, 2$)
G_j	shear modulus ($j = 1, 2$)
h	the initial height of sweat bridge
h_d	the equivalent height of sweat bridge
K	the overall stress intensity factors
$K1$	the stress intensity factors subjected to a pressure along part of the crack surface
$K2$	the stress intensity factors under the action of a far-field tensile stress
p	the capillary pressure of sweat bridge
$r_{L;R}$	the distance to the left or right tip of crack
S	the size of sweat bridge
$u_x;u_y$	displacement components
$\sigma_x;\sigma_y;\tau_{xy}$	stress components
γ	the surface tension of the sweat
δ	the thickness of the liquid-vapour interface
ε	the oscillation indexes
θ	polar coordinates based on the right tip of crack
$\theta_0;\theta_d$	the actual and equivalent contact angle of sweat bridge
ν_j	Poisson's ratio ($j = 1,2$)
σ_0	far-field tensile stress
σ_m	the far-field tensile stress which ruptures the sweat bridge
χ	the stress over the liquid-vapour interface
$\Delta 1$	the crack opening under the action of a pressure along part of the crack surface
$\Delta 2$	the crack opening under the action of a far-field tensile stress
$\Phi_j(z);\Psi_j(z)$	Goursat functions ($j = 1,2$)
$\overline{X}$	complex conjugate of parameter X
$\widetilde{X}$	dimensionless form of parameter X

And in this study, we investigate the effect of a liquid bridge on the crack opening and the stress intensity factor of an interface crack between skin and flexible membrane (such as silicone). At first, we theoretically analyse the solutions of an interface crack subjected to a uniform pressure along part of the crack surface by using the complex variable method. And then the crack opening displacement and the stress intensity factor of an interface crack under concurrent action of sweat bridge and far-field tensile stress are calculated by using the principle of superposition. Finally, numerical calculations have been carried out to show the influences of the sweat's location and size on the crack opening displacement and the stress intensity factors.

2. Formulation of the problem

Yu et al. [9] found that there is a saturation membrane thickness of millimetre scale. If the thickness is larger than the saturation value, the membrane can be regarded as a semi-infinite solid. Consider a stationary interface crack with a stationary liquid bridge in an infinite space shown as in Fig. 1.

By using the complex variable method [13,14], the solutions of the interface crack shown as in Fig. 1 depend on the four unknown complex functions $\Phi_j(z)$ and $\Psi_j(z)$, $j = 1,2$, of the complex variable $z = x + iy = re^{i\theta}$. The basic equations are

$$\begin{cases} (\sigma_x)_j + (\sigma_y)_j = 4\mathrm{Re}[\Phi_j(z)] \\ (\sigma_x)_j - (\sigma_y)_j + 2i(\tau_{xy})_j = 2[\bar{z}\Phi'_j(z) + \Psi_j(z)] \\ 2G_j(u_x + iu_y)_j = \eta_j \int \Phi_j(z)dz - z\overline{\Phi}_j(\bar{z}) - \int \overline{\Psi}_j(\bar{z})d\bar{z} \end{cases} \tag{1}$$

where η_j is $3-4\nu_j$ for plane strain and $(3-4\nu_j)/(1+\nu_j)$ for plane stress, G_j is shear modulus.

Before solving this problem, the oscillation index ε is defined as

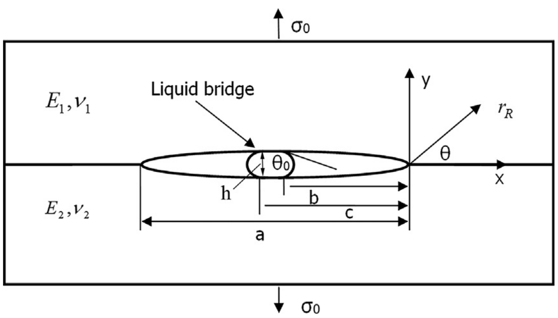

Fig. 1. Schematic of an interface crack with a liquid bridge in an infinite space.