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Electro-mechanical sliding frictional contact of a piezoelectric half-plane under a rigid conducting punch

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ABSTRACT

This paper investigates the two-dimensional sliding frictional contact of a piezoelectric half-plane in the plane strain state under the action of a rigid flat or a triangular punch. It is assumed that the punch is a perfect electrical conductor with a constant electric potential. By using the Fourier integral transform technique and the superposition theorem, the problem is reduced to a pair of coupled Cauchy singular integral equations and then is numerically solved to determine the unknown contact pressure and surface electric charge distribution. The effects of the friction coefficient and electro-mechanical loads on the normal contact stress, normal electric displacement, in-plane stress and in-plane electric displacement are discussed in detail. It is found that the friction coefficient has a significant effect on the electro-mechanical sliding frictional contact behaviors of the piezoelectric materials.

1. Introduction

In 1880, Jacques Curie and Pierre Curie discovered piezoelectric effects in some crystals, since then piezoelectric materials have been found a wide range of applications such as actuators and sensors in smart structures or systems due to their intrinsic electromechanical coupling effect. Extensive technical literatures concerning the piezoelectric materials can be found in the monographs [1,2].

Piezoelectric materials which are typical brittle materials may suffer from surface contact damage when subjected to a highly localized load exerted by a rigid body. Therefore, the contact mechanics of piezoelectric materials under the electro-mechanical loads has become an active research [3–10]. Sosa and Castro [11] investigated the fundamental solutions of a piezoelectric half-plane subjected to a concentrated line force and a concentrated line electric charge with the help of the state space approach. Giannakopoulos and Suresh [12] presented the general analytical theory for the frictionless contact problem of a piezoelectric half-space and both conducting and insulating punches were derived. Chen [13] studied the transversely piezoelectric half-space subjected to a rigid punch with an arbitrary profile by using the complex potential function method. Ramirez and Heyliger [14] and Ramirez [15] studied the contact response of an arbitrarily multilayered piezoelectric half-plane indented by a rigid frictionless parabolic punch based on a local/global stiffness matrix formulation. Wang et al. [16] examined the two-dimensional frictionless contact problem of the rigid conducting or insulating punches on a piezoelectric ceramic layer. They discussed the effect of the thickness of the piezoelectric layer on the stress and electric displacement, and the stress and electric displacement intensity factors at the punch tip. Chen and Yu [17] presented a

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detailed study on the adhesive contact between a spherical rigid punch on a piezoelectric half-space. The Maugis-Dugdale model was employed to describe the piezoelectric adhesive contact behavior. Guo and Jin [18] presented the adhesive contact behavior between a transversely isotropic piezoelectric half-space and a cylinder punch subjected to combined mechanical and electric loads under plane-strain condition. The effect of adhesion is described by using a generalized JKR model which can account for the non-slip condition in the contact regions. Wang et al. [19] conducted the frictionless contact problem for a piezoelectric film on an elastic substrate and discussed the influence of the Young's modulus and the Poisson's ratio of the elastic substrate on the solutions. Zhou and Lee [20] investigated the thermal contact problem of a piezoelectric strip with heat supply generated by the frictional tangential traction under the action of a rigid sliding punch. In their analysis, the punch was assumed as a perfect electrical insulator with zero electric charge distribution. They later presented a theoretical analysis of two-dimensional frictionless sliding contact over orthotropic piezoelectric materials indented by a rigid sliding punch using a real fundamental solution approach [21].

Recently, Ke et al. [22–24] extended the contact mechanics of homogeneous piezoelectric materials to functionally graded piezoelectric materials (FGPMs). Ke et al. [22,23] discussed the frictionless contact of the rigid insulating and conducting punches on the FGPM layered half-plane. The electro-elastic properties of the FGPM layer vary exponentially along the thickness direction. Later, they [24] studied the sliding frictional contact of a transversely isotropic FGPM layered half-plane under a rigid insulating punch. The results obtained in their works [22–24] indicated that the resistance to contact damage and electricity induced failure can be improved by adjusting the gradient index of the FGPM layer.

It should be pointed out that all aforementioned works didn't analyze the sliding frictional contact of piezoelectric materials acted by a conducting punch. To the best of the authors' knowledge, no report on this topic was found so far. The reason is that the sliding frictional contact between the piezoelectric materials and the conducting punch is more complex than the frictionless case. In particular, the sliding frictional case is governed by the coupled Cauchy singular integral equations of the 1st and 2nd kinds, which are quite difficult to solve analytically.

In this paper, the two-dimensional sliding frictional contact of a transversely isotropic piezoelectric half-plane under a rigid punch is investigated. It is assumed that the punch is a perfect electric conductor with a constant electric potential, and the friction in the contact region is Coulomb type. By using the Fourier integral transform technique and the superposition theorem, the problem is reduced to a pair of coupled Cauchy singular integral equations and then is numerically solved to determine the unknown contact pressure and surface electric charge distribution. A comprehensive parametric study is conducted to highlight the effects of both the friction coefficient and electro-mechanical loads on the contact behaviors of the piezoelectric materials.

2. Fundamental solutions of the piezoelectric half-plane

Consider the problem shown in Fig. 1 where a normal concentrated line force P, a tangential concentrated line force Q and a positive concentrated line electric charge Γ act on the surface of the piezoelectric half-plane with poling in z direction. The linear constitutive equations for a transversely isotropic piezoelectric half-plane under the plane strain state can be expressed in term of displacement components u_x and u_z and electric potential ϕ as

$$\sigma_{xx} = c_{11}\frac{\partial u_x}{\partial x} + c_{13}\frac{\partial u_z}{\partial z} + e_{31}\frac{\partial \phi}{\partial z}, \tag{1}$$

$$\sigma_{zz} = c_{13}\frac{\partial u_x}{\partial x} + c_{33}\frac{\partial u_z}{\partial z} + e_{33}\frac{\partial \phi}{\partial z}, \tag{2}$$

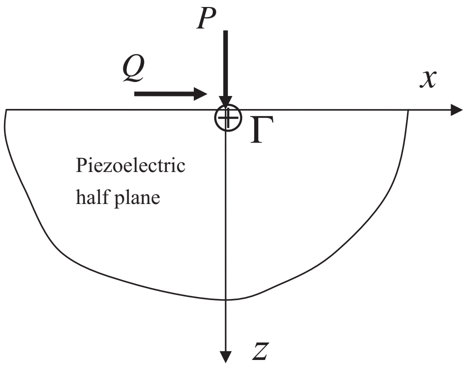

Fig. 1. A piezoelectric half-plane subjected to a normal line force P, a tangential line force Q and a positive line electric charge Γ.