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Two-dimensional thermoelastic contact problem of functionally graded materials involving frictional heating

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ABSTRACT

The two-dimensional thermoelastic sliding frictional contact of functionally graded material (FGM) coated half-plane under the plane strain deformation is investigated in this paper. A rigid punch is sliding over the surface of the FGM coating with a constant velocity. Frictional heating, with its value proportional to contact pressure, friction coefficient and sliding velocity, is generated at the interface between the punch and the FGM coating. The material properties of the coating vary exponentially along the thickness direction. In order to solve the heat conduction equation analytically, the homogeneous multi-layered model is adopted for treating the graded thermal diffusivity coefficient with other thermo-mechanical properties being kept as the given exponential forms. The transfer matrix method and Fourier integral transform technique are employed to convert the problem into a Cauchy singular integral equation which is then solved numerically to obtain the unknown contact pressure and the in-plane component of the surface stresses. The effects of the gradient index, Peclet number and friction coefficient on the thermoelastic contact characteristics are discussed in detail. Numerical results show that the distribution of the contact stress can be altered and therefore the thermoelastic contact damage can be modified by adjusting the gradient index, Peclet number and friction coefficient.

1. Introduction

Functionally graded materials (FGMs) are usually a mixture of two distinct material phases with continuously varying volume fractions of constituent materials, hence their effective material properties change in a continuous and smooth manner. Used as coatings or interfacial zones, they can reduce the magnitude of residual and thermal stresses, mitigate stress concentration and increase fracture toughness (Suresh and Mortensen, 1998). In the past few years, the contact behaviors of FGMs have been concerned by many investigators. Many experimental and numerical results have shown that a properly controlled material property gradient in the FGM can lead to a significant improvement in the resistance to contact deformation and damage (cf. Suresh et al., 1999; Pender et al., 2001; Suresh, 2001). Giannakopoulos and Suresh (1997a,b) considered the axisymmetric contact problems of the graded half-space subjected to the flat, spherical and conical indenters, respectively. Guler (2001, 2004, 2006, 2007) examined the frictional contact problems of the FGM coated substrate acted by a rigid punch or contact problems between two deformable elastic solids with graded coatings. Wang and his co-authors developed the linear multilayered model to analyze the plane (Ke and Wang, 2006, 2007a), axisymmetric (Liu and Wang, 2009) and fretting (Ke and Wang, 2007b,c, 2010) contact problems of FGMs. They discussed the potential application of the FGM coating to modify the contact damage and fretting fatigue under the condition of sliding and fretting. El-Borgi and his co-authors solved the plane and axisymmetric receding contact problems of FGMs (El-Borgi et al., 2006; Rhimi et al., 2009) and the partial slip contact of FGMs (Kallel-Kamoun et al., 2010; Elloumi et al., 2010). Recently, Dag et al. (2009) developed the analytical and computational methods for contact mechanics analysis of FGMs with the elastic gradient in the lateral direction. Choi and Paulino (2010) analyzed the coupled plane elastic problems of crack/contact mechanics for a coating/substrate system with functionally graded properties.

It should be pointed out that the above studies have not taken into account the thermal effect on the contact behaviors of FGMs. Actually, in the sliding frictional contact problems, a significant amount of frictional heating may be generated due to the frictional sliding between the two contact bodies, which in turn leads to the thermoelastic distortion and contact damage at the contacting surface. In addition, temperature rise induced from the sliding frictional contact may considerably influence the performance of the FGM coated structures. For instance, a severe temperature rise may cause surface deterioration, oxidation, or even melting in some cases (Shi, 2001). Indeed, the aforementioned works have demonstrated that FGMs have the potential to reduce the

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