Journal of the Mechanics and Physics of Solids 95 (2016) 517–529

Contents lists available at ScienceDirect

Journal of the Mechanics and Physics of Solids

journal homepage: www.elsevier.com/locate/jmps

Effect of thickness and boundary conditions on the behavior of viscoelastic layers in sliding contact with wavy profiles

N. Menga [a,*], L. Afferrante [a], G. Carbone [a,b,c]

[a] Department of Mechanics, Mathematics and Management, Politecnico di Bari, V. le Japigia, 182, 70126 Bari, Italy
[b] CNR - Institute for Photonics and Nanotechnologies U.O.S. Bari, Physics Department "M. Merlin", via Amendola 173, 70126 Bari, Italy
[c] Imperial College London, Department of Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

ARTICLE INFO

Article history:
Received 17 March 2016
Received in revised form
13 June 2016
Accepted 17 June 2016
Available online 20 June 2016

Keywords:
Contact mechanics
Viscoelasticity
Friction
Fracture mechanics

ABSTRACT

In this work, the sliding contact of viscoelastic layers of finite thickness on rigid sinusoidal substrates is investigated within the framework of Green's functions approach. The periodic Green's functions are determined by means of a novel formalism, which can be applied, in general, to either 2D and 3D viscoelastic periodic contacts, regardless of the contact geometry and boundary conditions.

Specifically, two different configurations are considered here: a free layer with a uniform pressure applied on the top, and a layer rigidly confined on the upper boundary. It is shown that the thickness affects the contact behavior differently, depending on the boundary conditions. In particular, the confined layer exhibits increasing contact stiffness when the thickness is reduced, leading to higher loads for complete contact to occur. The free layer, instead, becomes more and more compliant as thickness is reduced.

We find that, in partial contact, the layer thickness and the boundary conditions significantly affect the frictional behavior. In fact, at low contact penetrations, the confined layer shows higher friction coefficients compared to the free layer case; whereas, the scenario is reversed at large contact penetrations. Furthermore, for confined layers, the sliding speed related to the friction coefficient peak is shifted as the contact penetration increases. However, once full contact is established, the friction coefficient shows a unique behavior regardless of the layer thickness and boundary conditions.

1. Introduction

Rubber-like materials have found increasing utilization in the last few decades in many practical applications, such as tires, seals, conveyor and power transmission belts. The growing interest in polymeric materials, strongly supported by industrial demands, has boosted the scientific effort in such field of materials. The demanding problem of an accurate modelling of the contact behavior has been addressed by analytical approaches (Hunter, 1961; Grosch, 1963; Persson, 2001, 2010; Panek and Kalker, 1980; Harrass et al., 2010; Menga et al., 2014), numerical sophisticated simulations (Carbone and Putignano, 2013; Padovan and Paramadilok, 1984; Padovan, 1987; Padovan et al., 1992; Nasdala et al., 1998; Le Tallec and Rahler, 1994; Menga and Ciavarella, 2015; Dimaki et al., 2016) and experimental investigations (Schapery, 1969; Faisca et al., 2001; Odegard et al., 2005; Carbone et al., 2009; Martina et al., 2012).

* Corresponding author.
E-mail address: nicola.menga@poliba.it (N. Menga).

http://dx.doi.org/10.1016/j.jmps.2016.06.009
0022-5096/

One of the most common assumptions in contact mechanics is that the contact bodies can be well represented by semi-infinite solids. This idea holds true for a large class of contact mechanics problems, as confirmed by theoretical arguments and experimental evidences. For instance, in the case of Hertzian contacts, it can be shown that, if the size of the contact area is sufficiently small compared with the thickness of the elastic bodies, the contact quantities can be correctly predicted by modelling the bodies as half-spaces.

However, when dealing with contacts involving thin layers, where the contact characteristic length is comparable with the layer thickness, the half-space assumption fails and the semi-infinite model is no longer able to correctly address the contact problem. Moreover, in the case of viscoelastic materials employed in power transmission belts, seismic energy dissipation systems, tires, just to enumerate a few examples, the amount of dissipated energy and, in turn, the tribological properties of the contact are indeed strongly affected by the thickness.

For this reason, here we extend the results obtained by Menga et al. (2014) for a viscoelastic half-plane in sliding contact with a periodic wavy profile, to the case of viscoelastic layers. In particular, we focus on two different configurations: a viscoelastic layer rigidly confined on the upper boundary and a free layer uniformly loaded on the top.

Such apparently simplified contact configurations provide a powerful tool to investigate more complicated contact configurations. Hence, the proposed solution can be exploited in multi-scale approaches (e.g. Ciavarella et al., 2000; Afferrante et al., 2015) to capture the features of the viscoelastic contact of real randomly rough surfaces, which are the main focus of interest in modern contact mechanics (Persson, 2001, 2010, 2006; Campana et al., 2008, 2011; Putignano et al., 2012; Afferrante et al., 2012; Putignano et al., 2013). Moreover, following the path firstly proposed by Burmister (1945a, 1945b, 1945c), interesting results may be obtained even in the field of layered materials, by exploiting the solutions provided by Persson (2012) and Zhang and Zhenze (2011).

Under the assumption of steady sliding and taking into account linearity and translational invariance, the contact problem can be mathematically formulated in terms of a Fredholm integral equation of the first kind. However, since the value and the position of the contact area are not known a priori, two additional conditions are required. Such conditions can be obtained by observing that the mode I stress intensity factor K_I at the trailing and leading edges of the contact must vanish (Charmet and Barquins, 1996; Shull, 2002; Carbone and Mangialardi, 2004).

2. The problem formulation

Fig. 1 shows the sliding contact between a slightly wavy rigid profile with amplitude Λ and wavelength λ, and a viscoelastic layer of thickness h. As already mentioned, two different configurations are considered: a *free layer* with a uniform

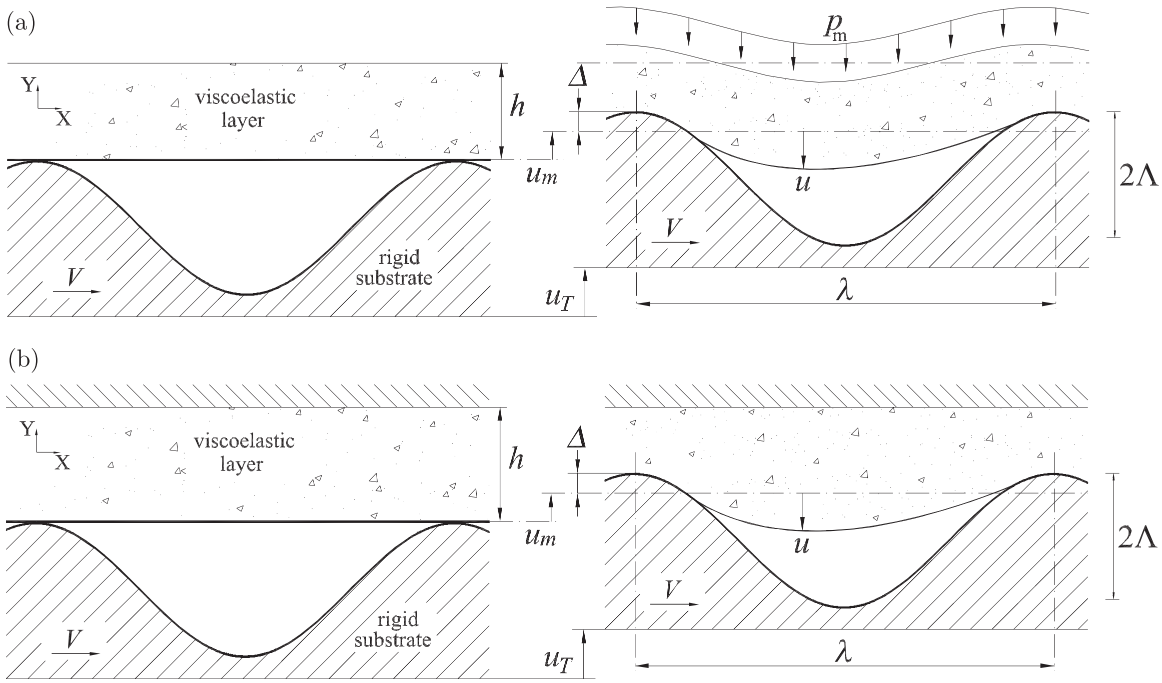

Fig. 1. The sliding contact of a viscoelastic layer of thickness h with a rigid slightly wavy profile. Different boundary conditions on the upper face are considered: (a) free layer (model A); (b) confined layer (model B). Tangential interactions at the interface are neglected. In particular, Δ is the contact penetration, u is the layer normal displacement measured from the mean line of the deformed profile, and $u_T = \Delta + u_m$ is the total normal displacement of the rigid intenter.