Reliability of Micromechanical Contact Models: a Still Open Issue

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Abstract The assumption of perfectly flat surfaces within the context of the contact problems constitutes very often an oversimplification of the reality. In fact, when real surfaces are examined more in details, roughness can be found at different scale lengths. This fundamental feature poses enormous difficulties on the mathematical modeling of the physics of the contact problems. Nevertheless, the study of the effect of the multiscale roughness on the contact predictions is crucial from the engineering point of view. To deal with this problem several micromechanical contact models have been developed since the middle of the 19th Century. Such models are based on very different mathematical frameworks, with a consequent lack of standardization. The recent perspective to apply such models to smaller and smaller scale lengths, down to the nanoscale, makes the reliability of these models a still open issue. The basic aim of this chapter is to provide a detailed review of the most popular contact models available in the literature. Moreover we focus one the crucial intent of providing a degree of confidence about the differences between the contact predictions provided by the models. For this purpose a critical comparison of the outcomes of such models by applying them to numerically generated rough surfaces is then proposed.

1 Introduction

This chapter deals with the problem of contact between random rough surfaces. By increasing the applied normal load, the highest asperities of the rough surfaces come into contact. From there, an evolution of both the number and the size of these small contact areas (spots) takes place. The sum of all the spots gives the real contact area, which is always a small percentage of the nominal one for the usual range of engineering materials and applied loads. The importance of the prediction of the real contact area has been recognized since the earliest studies on Contact Mechanics. In fact, from the engineering point of view, an accurate description of the contact problem is crucial for a better

†The financial support of the European Union to the Leonardo da Vinci Project I/06/B/F/PP-154069 “Innovative Learning and Training on Fracture (ILTOF)” and of the Italian Ministry of University and Research to the project PRIN2005 “Modelling and approximation in advanced mechanical problems” is gratefully acknowledged.
understanding of of friction and wear. This is true also for many other contact phenomena, like, e.g., electrical and thermal conductance. Moreover, an additional complexity is represented by the several scale lengths involved in the problem, since many surfaces show a roughness ranging from the milli- to the nano-scale (Paggi, 2005; Carpinteri and Paggi, 2005, 2007).

From the computational point of view, the main consequence of the surface roughness concerns the possibility to establish a constitutive law for the interface, i.e. a load-displacement relationship which rules the mean planes distance as a function of the applied pressure. Within the Finite Element context this modern approach to the normal contact discretization was firstly issued by Zavarise and coworkers (Zavarise, 1991; Zavarise et al., 1992a,b). It provides a physical ground to the techniques used in Computational Mechanics to enforce numerically the satisfaction of the unilateral contact constraints; see also some recent applications in (Wriggers, 2002; Wriggers and Zavarise, 2004; Paggi et al., 2006; Carpinteri et al., 2005).

Concerning the micromechanical contact theories based on a statistical approach, several of them have been proposed in the last decades, since the middle of the ’60s. Among them, we mention for their importance the Greenwood & Williamson’s elastic model (Greenwood and Williamson, 1966), its recent extension to the elasto-plastic behavior by Sridhar and Yovanovich (Sridhar and Yovanovich, 1994), the Mikic’s elastic model (Mikic, 1974), and the Cooper, Mikic & Yovanovich’s plastic one (Cooper et al., 1968).

The application of these models to real interfaces leads to important questions regarding the problem of surface sampling, and still makes the reliability of micromechanical contact models an open issue. Using both the old profilometer technique, which moves a stylus over a sample length of the surface, and the modern 3D laser-scanning techniques, the continuous function of heights is sampled at discrete intervals of length. The obtained discrete curve is then analyzed from a statistical point of view on the basis of the random process theory. As a result, two main difficulties arise and have been the subject of extensive research in the past. On one hand, an ambiguity exists on the choice of the population that is used to compute the statistical parameters, with a corresponding lack of standardization. A basic difference, for instance, is embedded in the choice of using a 2D or a 3D surface restitution. It is easy to see that the peaks of a 2D profile not always correspond to summits of a 3D one. On the other hand, the statistical parameters are resolution dependent, being functions of the sampling interval. As a result, contact predictions are resolution-dependent, since the statistical parameters are used as the primary input variables for the micromechanical contact models.

In this context, the use of fractal geometry has been very appealing for the development of multiscale contact models (see also Borri-Brumetto et al. (2006) for a detailed overview). A first attempt to develop a contact model on the basis of fractal concepts is due to Majumdar and Bhushan (1990). Then Borri-Brumetto et al. (1999a,b) demonstrated, by means of a deterministic elastic numerical analysis, that the total predicted real contact area decreases when more details of a rough surface with fractal properties are taken into account. This suggests that, in the limit of a vanishing sampling interval, i.e. an infinite resolution of the profilometer used for scanning the surface, the contact would consist in an infinite number of infinitesimal contact spots, which results into a zero total area. More recently, similar results were also derived by Ciavarella et al.