Direct numerical simulation of rough microcontacts under normal load

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Abstract

The determination of the real contact area is important for many high-precision applications and measurement tasks. Microparts with radii of curvature of 100 µm, and less, show typical wavelengths for roughness, form and waviness, which go beyond the conventional scale. Hence, proven contact models for the macroscopic case should be verified with respect to the geometric scale and material properties. The new approach presented here employs topographies from Atomic Force Microscope (AFM) measurements and circumvents micro-geometric models. The numerical simulation determines the deformation of the elastic half-space. Plastic deformation may occur locally on the surface. Novel models for the plastically deformed surface are introduced and compared.

1 Introduction

The numerical simulation of the contact area of smooth microscale bodies, as presented in [1], is extended here by the implementation of topographies of AFM measurements. Thus a numerical simulation is realized, which avoids a micro-geometric model and, furthermore, provides two different novel models of plastic deformation.

2 Methods

The contact of a ruby sphere and of an optical flat is examined. The diameter of the sphere is 200 µm; for the computation, Young’s modulus is 430 GPa and Poisson’s ratio is 0.25 for both. Maximum normal load applied is approx. 200 mN. The complete flow chart of the simulation is shown in figure 1. In addition to the solution of the elastic problem in [1], the restart path incorporates the monitoring of the plastic impact.

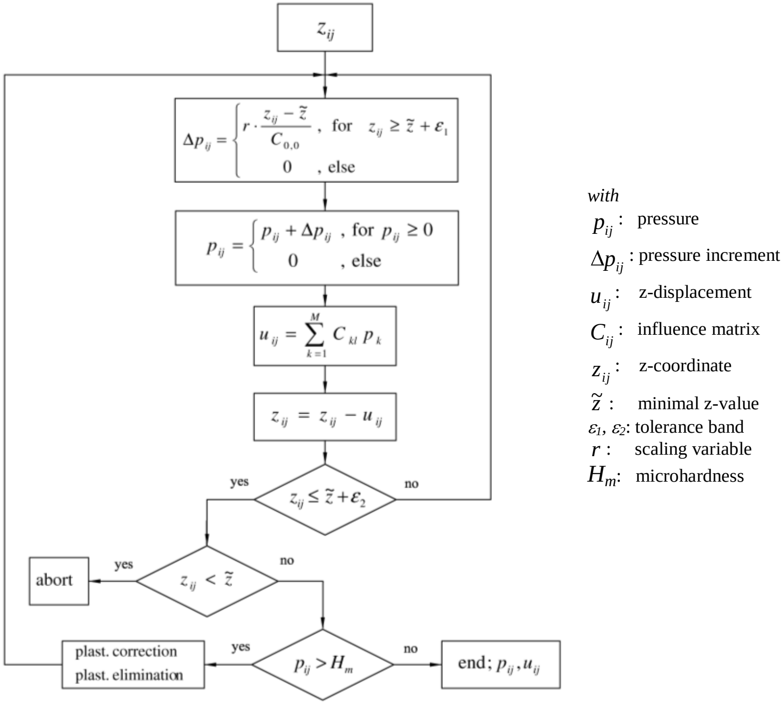

Figure 1: Flow chart of a computer program for elastic-plastic deformation

If the local pressure exceeds a critical pressure $p_{ij}>H_m$, see [2], the change of topography can be modelled by two different mechanisms. First, the "plastic elimination" is represented by a volume loss associated with the idea of a predominantly brittle process.

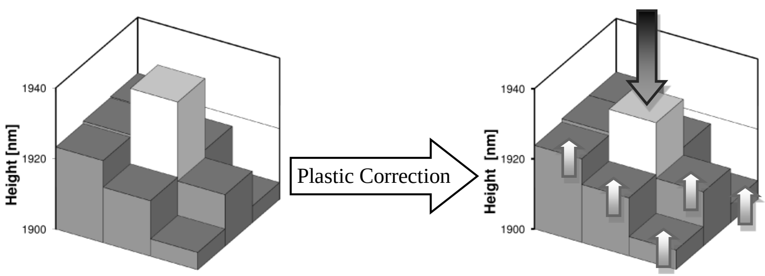

Figure 2: Sketch of plastic correction

Hence the height of a single element under a normal load is reduced to the height of the next lower of the surrounding 8 elements, see figure 2 left. As a second method, the plastic deformation of a central element is modelled in a similar manner to a yielding mechanism. Here it is denoted as plastic correction. The same volume as that of the plastic elimination is distributed to all the 9 neighbouring elements in equal measure here, see figure 2. The iteration is started again with a new topography after correction.

3 Results and Discussion

A visualization of the elastic-plastic deformation is shown in figure 3. For clarity, the deformation is applied to the sphere only. The normal load is 445 mN.

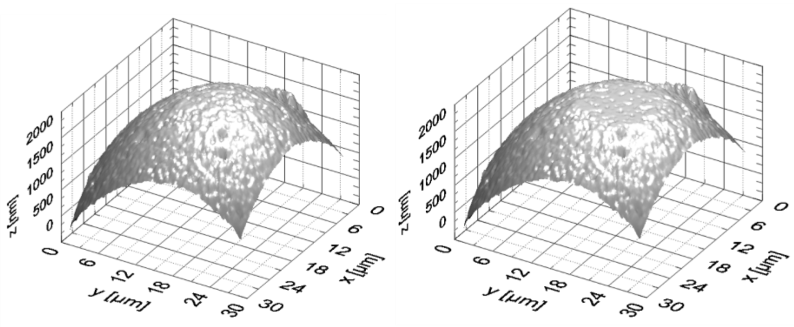

Figure 3: Visualization of the numerical simulation; left: Undeformed topography; right: Sphere under load; resolution 128 X 128 elements, 220 are plast. affected

In the analysed range of parameters, single local pressures always exceed the elastic range. The amount of plastic deformation related to the theoretical elastic contact area is shown in figure 4. For both plastic models this relative plastic contact area decreases with an increasing element size. Furthermore, for lower normal loads, the relative plastically deformed area calculated with plastic correction is approx. 5 times larger than the area calculated with plastic elimination. The correlation between real contact area A_r and applied normal load F is $A_r \propto F^{0.88}$, using the plastic correction model, see figure 4, right. It should be noted that this result is close to Archard's model of "protuberances on protuberances", which leads to an exponent of 8/9, see, e.g. fig. 2c in [3].

4 Conclusions and Outlook

A direct numerical simulation of the rough microcontact is presented. Two different novel models for plastic deformation are compared. Their results differ significantly for lower normal loads. In a next step, the elliptical rough contact will be examined and the results will be compared to experimental results, e.g. [4]. The influence of the plastic deformation mode will then be discussed.

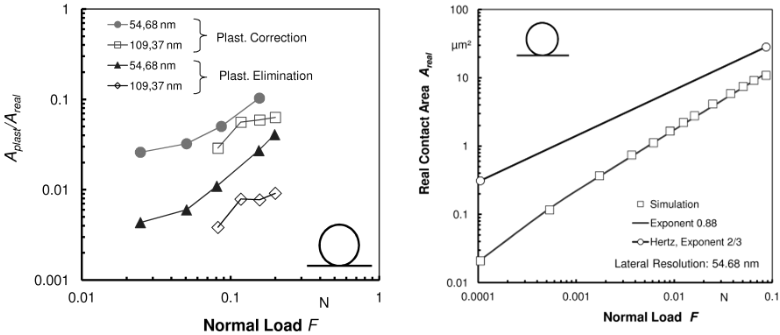

Figure 4: Left: Comparison of plastic correction and plastic elimination for different resolutions of the simulation; right: Real contact area as a function of normal load

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