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A mechanistic understanding of the wear coefficient: from single to multiple asperities contact

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Abstract

Sliding contact between solids leads to material detaching from their surfaces in the form of debris particles, a process known as wear. According to the well-known Archard wear model, the wear volume (i.e. the volume of detached particles) is proportional to the load and the sliding distance, while being inversely proportional to the hardness. The influence of other parameters are empirically merged into a factor, referred to as wear coefficient, which does not stem from any theoretical development, thus limiting the predictive capacity of the model. Based on a recent understanding of a critical length-scale controlling wear particle formation, we present two novel derivations of the wear coefficient: one based on Archard's interpretation of the wear coefficient as the probability of wear particle detachment and one that follows naturally from the up-scaling of asperity-level physics into a generic multi-asperity wear model. As a result, the variation of wear rate and wear coefficient are discussed in terms of the properties of the interface, surface roughness parameters and applied load for various rough contact situations. Both new wear interpretations are evaluated analytically and numerically, and recover some key features of wear observed in experiments. This work shines new light on the understanding of wear, potentially opening a pathway for calculating the wear coefficient from first principles.

Keywords: wear coefficient; contact; cluster statistics; self-affine surface

1. Introduction

The scientific study of wear dates back to the early 19$^{\text{th}}$ century [18], but our current understanding was built upon research conducted in the middle of the last century [5]. Wear comes in various forms, with adhesive wear, the process of detachment of surface asperities tip by adhesive forces during the sliding contact of two solids, being one of the most prominent. Systematic wear experiments in the mid-20$^{\text{th}}$ century [3, 6] suggested a general relation where the wear rate (i.e. wear volume per unit sliding distance) is linearly proportional to the applied normal load, in a certain range of the latter [6, 43], and related to the hardness of the material. Inspired by this experimental evidence, Archard [3] generalized Holm's concept of "atom removal" [20] to "debris removal" and pictured an adhesive wear model. He assumed that an asperity junction of radius a produces a debris volume proportional to a^3 over an effective sliding distance of $2a$, giving a linear relationship between wear rate and real contact area at the asperity level. To extend this single-asperity relation to a multi-asperity contact, Archard argued that only a fraction of contacting asperities, a quantity referred to as the "wear coefficient", produces wear particles. This conception of the "wear coefficient" being key in understanding wear, Archard and Hirst [4] claimed that "…one of the most important problems in an understanding of wear is to explain the magnitude of the probability of the production of a wear particle at an asperity encounter." This long-standing problem has remained unresolved, and evaluation of the wear coefficient is still relying on empirical data, with no insight from a physical model.

Similarly to the friction coefficient [47], the wear coefficient is a system property that depends on many parameters including applied load [51, 44], material properties of sliding bodies (e.g. fracture toughness [15, 9])

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