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Long term wear of complete contacts subject to fretting

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ABSTRACT

The fully worn configuration of complete, square-edged contacts subject to fretting fatigue is found using a local asymptote, and this is applied to a specific example problem. There are three possible forms of solutions: (a) all wear is averted, (b) there is a finite amount of wear to a stable, fully adhered contact and (c) progressive wear gradually eroding the whole contact. The conditions under which each of these is the anticipated response are revealed.

1. Introduction

Fretting occurs when there is cyclic slip between contacts in notionally static contact. The phenomenon causes surface modification and encourages the nucleation of fatigue cracks, and it also causes erosion and wear. The processes of nucleation and surface modification occur in parallel, so that we observe, usually, a relatively rapid rise in the coefficient of friction followed by crack nucleation and wear which may take place over hundreds of thousands or millions of cycles. In this paper we look at the problem of what happens when there is relatively severe wear – or a high rate of wear – and the object is to try to deduce the final geometry of the contact, so revealing the contact pressure distribution which gives rise to crack nucleation. This may be done without appealing to a specific, calibrated wear law, other than the assumption that, wherever there is compression and surface slip, wear will occur. This has already been done for a range of incomplete contacts, both axisymmetric and plane [1,2], and it has been shown that the final contact patch is always the same as the initial stick zone for the unworn problem [3]. Here, we intend to extend the investigation to complete contacts where we do not expect a similar result because of the high degree of inherent coupling present.

The example problem to be analysed is shown in Fig. 1.

It is a square elastic block, of side $2a$ pressed by a constant normal force, P, onto an elastically similar half-plane and subject to a monotonically increasing shearing force, Q. Because we anticipate that the contact will be fully adhered under a wide range of conditions (see the paper by Churchman and Hills [4]) we concentrate our attention on the near-contact edge state of stress which we model using a standard Williams asymptotic solution for the case where the 'wedge' interior angle is $3\pi/2$ rad, i.e. the sum of the pad and half-plane domains. We will examine the problem of slip and wear in the context of the asymptote, for generality, and then 'paste' the solutions found back into the specific pad problem described.

2. Williams solution

For a complete description of the Williams recipe [5] the extended description provided by Barber [6] is recommended. It is known that, in terms of a power series expansion of the state of stress about the apex there are two dominant, singular terms; the more strongly singular is symmetrical with respect to the wedge symmetry line (Fig. 2(a)),

whilst the second term is antisymmetric. In the standard nomenclature of the subject we may write down the local state of stress as

$$\begin{aligned}\sigma_{\theta\theta}\left(r,\theta\right) &= K_I r^{\lambda_I-1} f^I_{\theta\theta}(\theta) + K_{II} r^{\lambda_{II}-1} f^{II}_{\theta\theta}(\theta)\\ \sigma_{r\theta}\left(r,\theta\right) &= K_I r^{\lambda_I-1} f^I_{r\theta}(\theta) + K_{II} r^{\lambda_{II}-1} f^{II}_{r\theta}(\theta)\end{aligned} \quad (1)$$

where the scaling is chosen such that

$$\begin{aligned} f^I_{\theta\theta}(0) &= 1 \qquad f^I_{r\theta}(0) = 0\\ f^{II}_{\theta\theta}(0) &= 0 \qquad f^{II}_{r\theta}(0) = 1\end{aligned} \quad (2)$$

and, for the case of a wedge of internal angle $3\pi/2$ (the contact corner adhered to a half-plane)

$$\lambda_I = 0.5445 \qquad \lambda_{II} = 0.9085. \quad (3)$$

Although this pair of base vectors is the natural one to chose for a notch, because the solutions are uncoupled along the bisector, it

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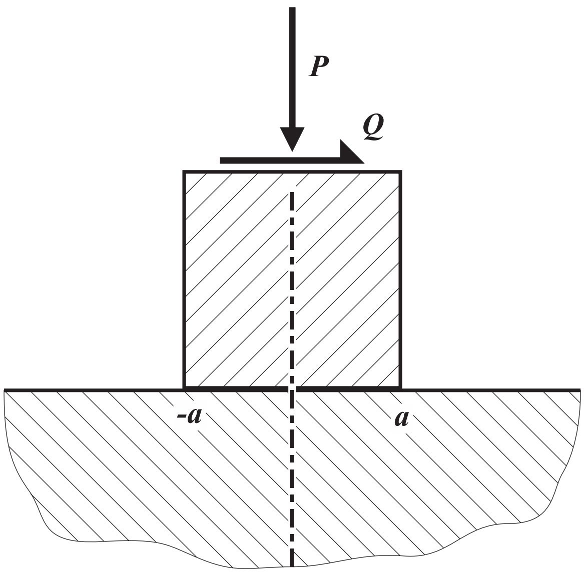

Fig. 1. Geometry of example problem.

is preferable in contact problems to re-set them along the interface, $\theta = \pi/4$, so that we may write

$$p \equiv \sigma_{\theta\theta}\left(r, \pi/4\right) = K_I^0 r^{\lambda_I - 1} + K_{II}^0 r^{\lambda_{II} - 1} \quad (4)$$

$$q \equiv \sigma_{r\theta}\left(r, \pi/4\right) = K_I^0 r^{\lambda_I - 1} g_{r\theta}^I + K_{II}^0 r^{\lambda_{II} - 1} g_{r\theta}^{II}, \quad (5)$$

where

$$g_{r\theta}^I = 0.543 \qquad g_{r\theta}^{II} = -0.219. \quad (6)$$

This, then, fully specifies the state of stress adjacent to a contact corner, when it is fully adhered, in terms of the generalised stress intensity factors K_I^0, K_{II}^0.

3. Solution within the asymptote

We shall only be concerned, here, with solutions where the applied loads are such that full contact is always maintained. As $0 < \lambda_I < \lambda_{II}$ it follows that as the contact corner is approached the symmetric term will dominate the solution and, as $r \to 0$ the requirement for contact to be maintained right to the edge is that $K_I^0 < 0$. When the asymptote is attached to the finite problem this will put a bound of the permissible combinations of Q/P. Now, if the coefficient of friction, f, exceeds $g_{r\theta}^I$ the contact will remain adhered to its extreme edge, and no wear will be possible. Under these circumstances the contact will provide only a 'notch intensification',

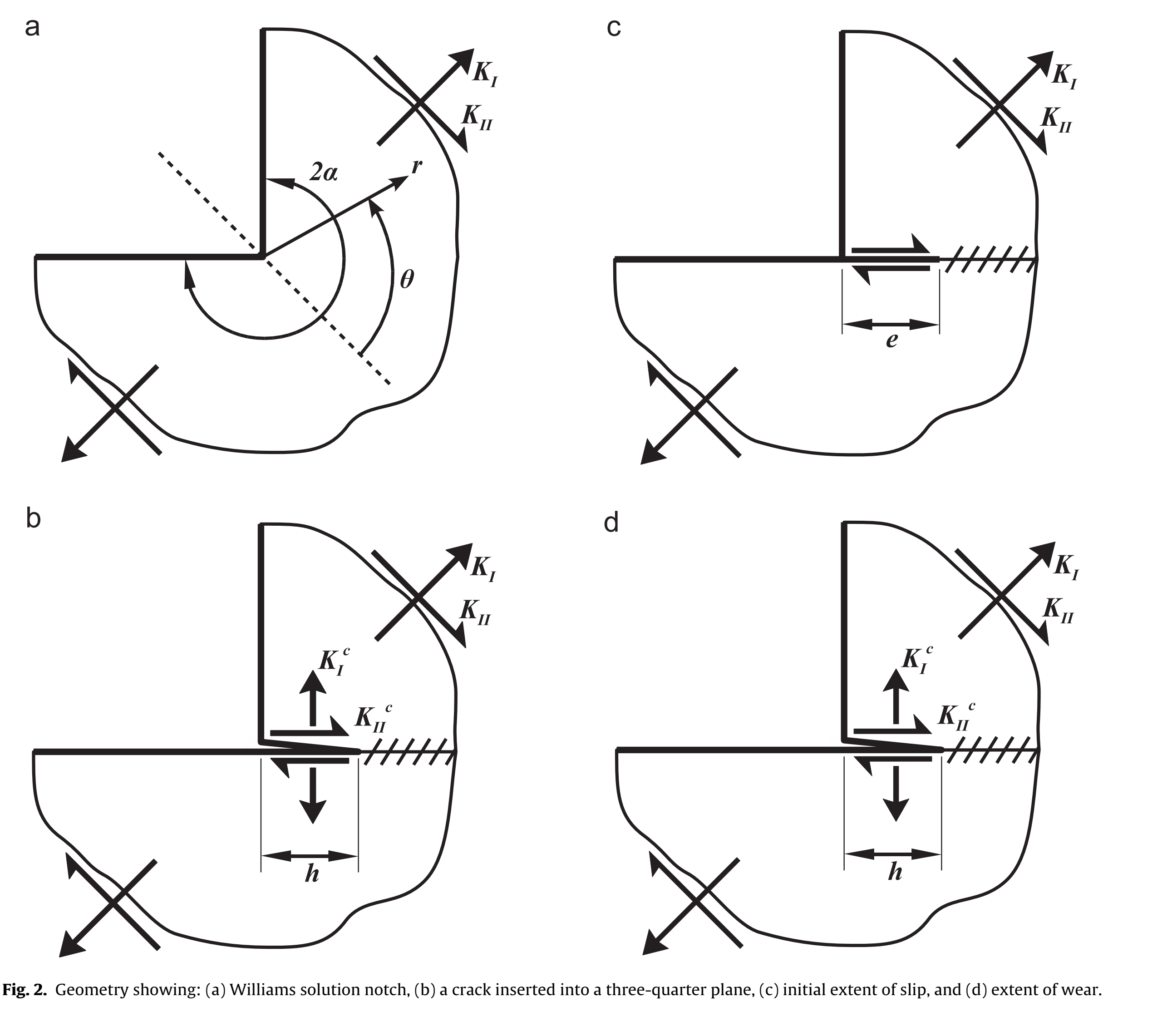

Fig. 2. Geometry showing: (a) Williams solution notch, (b) a crack inserted into a three-quarter plane, (c) initial extent of slip, and (d) extent of wear.