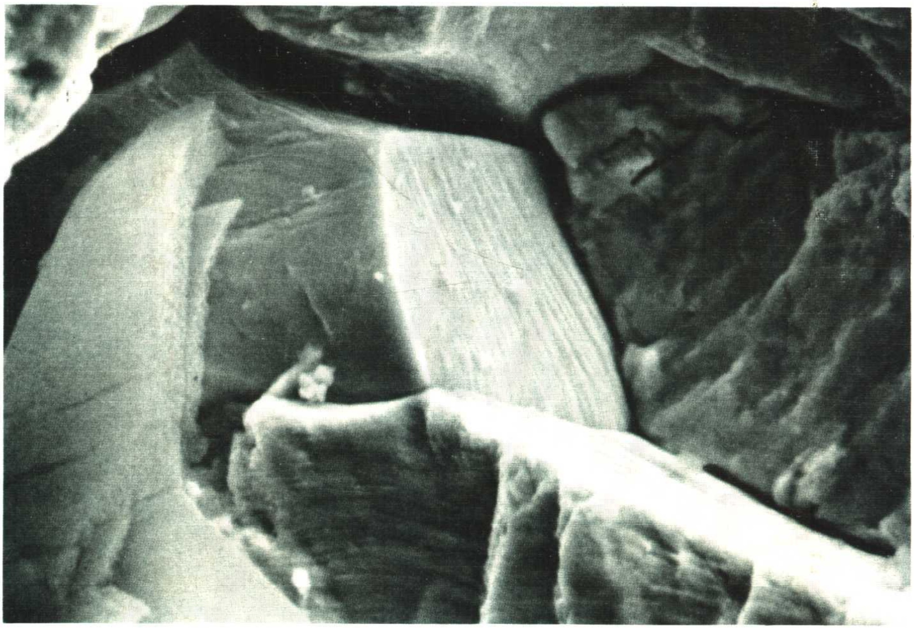
MICROSTRUCTURAL SCIENCE
VOL. 13

Corrosion, Failure Analysis, and Metallography



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AMERICAN SOCIETY FOR METALS
INTERNATIONAL METALLOGRAPHIC SOCIETY

Microstructural Science
Volume 13

Corrosion, Failure Analysis, and Metallography

Proceedings of the Seventeenth Annual Technical Meeting of the International Metallographic Society

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PREFACE

Volume 13 of the Microstructural Science series records the technical presentations made at the 17th Annual IMS Technical Meeting of the International Metallographic Society (IMS) held at the Hershey Philadelphia Hotel, Philadelphia, Pennsylvania, July 15-18, 1984.

The papers presented provide information on a broad range of microstructural topics. Seven papers describe various aspects of microhardness testing and some of its many applications. Sixteen papers are devoted to a wide range of physical metallurgy - microstructural - metallographic topics concerning numerous materials—stainless steels, aluminum, zirconium, irons and steels, thoria fuels, dental amalgams, Ni_4Mo, and vanadium, for example. Seven articles describe a variety of corrosion problems under a wide range of conditions. The final nine papers describe studies of failures of materials ranging from semiconductors to a tantalum heat exchanger. Fractographic procedures are emphasized in several of these studies.

The annual IMS meeting also hosted the judging and premier showing of the International Metallographic Exhibit (sponsored jointly by IMS and the American Society for Metals). The exhibit maintained the high standards of technical and aesthetic quality for which it is internationally recognized. The exhibit awards are listed at the conclusion of this volume.

The 17th meeting began with a two-day "Microindentation Hardness" symposium which included workshop sessions and demonstrations. The symposium was organized by P.J. Blau and B.R. Lawn and was cosponsored by IMS and ASTM.

The success of this meeting was the result of the efforts of many persons. The meeting was convened by James E. Bennett, President of IMS. Co-General Chairmen for the meeting were Chris Bagnall and Robert E. Witkowski. The technical program chairman and vice-chairman were Stuart A. Shiels and M.R. "Mac" Louthan, respectively. The International Metallographic Exhibit was co-chaired by Robert C. Muir and Robert S. Crouse.

Donald W. Stevens and Richard K. Ryan organized the commercial equipment exhibit.

For Volume 13, editing was primarily the responsibility of George F. Vander Voort. Mrs. Anne Louise Egan typed the camera-ready copy for our publisher, the American Society for Metals. The success of this volume is also the result of the participating IMS members, their colleagues, and their sponsoring organizations which permitted presentation of their work at this meeting.

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R.E.Witkowski and G.F.Vander Voort

FRACTURE INDENTATION BENEATH A FLAT PUNCH

R. Mouginot* and D. Maugis**

ABSTRACT

The mechanics of crack initiation and propagation beneath an axisymmetric flat punch is investigated on the basis of Lawn's and Roesler's studies. The stress tensor was given by Sneddon (1946). The strain-energy release rate G is computed by numerical integration as a function of both the crack length and its relative starting radius.

We show that the starting radius of the crack corresponds to the flaw position where G is maximum. The different stages of crack equilibrium are analysed. A generalized Auerbach's law is found and this approach is compared with Hertzian fracture.

Experimental results on optical glass confirmed most points of the theory and are discussed.

INTRODUCTION

Circular flat punches have been used many times [1-6] to study fracture indentation. Compared with spherical punches, the advantage is a constant radius of contact during loading.

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However, the theorectical analysis has never been done, presumably because the authors were unaware of the stress tensor computed by Sneddon [7] (with misprints later corrected by Barquins and Maugis [8]).

The method is similar to that followed for Hertzian fracture [9-11]:

1. Compute and draw stress trajectories starting from various distances from the edge of the contact,

2. Compute and draw principal tensile stress σ (b) along stress trajectories,

3. Assume that the crack follows stress trajectories, and compute the stress intensity factor by

$$K_I = \frac{2}{\pi^{\frac{1}{2}}} c^{\frac{1}{2}} \int_0^c \frac{\sigma(b)db}{(c^2-b^2)^{\frac{1}{2}}} \tag{1}$$

and the strain energy release rate by

$$G = \frac{1 - \nu^2}{E} K_I \tag{2}$$

where c is the crack length, ν the Poisson ratio, and E the Young's modulus. Numerical calculation have been performed for $\nu = 0.22$; and,

4. Study the equilibrium, crack by the Griffith criterion $G = 2\gamma$, where γ is the intrinsic surface energy.

INITIATION OF FRACTURE

Let a be the radius of the punch. Stress trajectories are given in Figure 1, and the distribution of the principal stress σ(b) along various stress trajectories (starting from various r/a) is given in Figure 2. Assuming a uniform distribution of flaws of length c_f, it is evident from the rapidly decreasing stress at small r/a, that surface flaws just near the edge of the contact can hardly be activated compared with outer surface flaws.

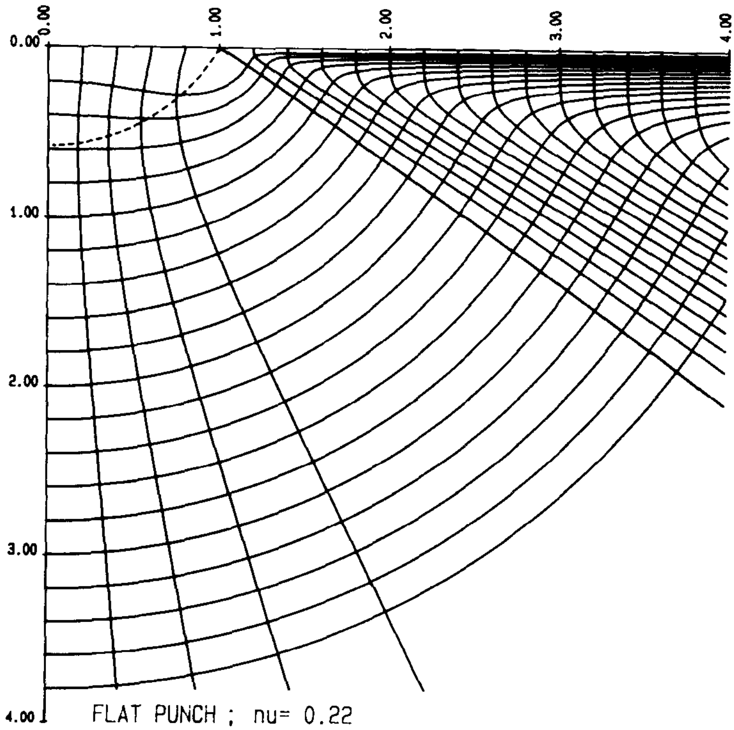

Figure 1. Stress trajectories under a flat punch of radius a.

Writing the stresses in the general form

$$\sigma\left(\frac{r}{a},\frac{z}{a}\right) = \frac{P}{\pi a^2}\, f\left(\frac{r}{a},\ \frac{z}{a}\right)$$

G has the general form

$$G = \frac{4}{\pi^3}\ \frac{1-\nu^2}{E}\ \frac{P^2}{a^3}\left[\phi\left(\frac{c}{a}\right)\right]_{r/a} \tag{3}$$

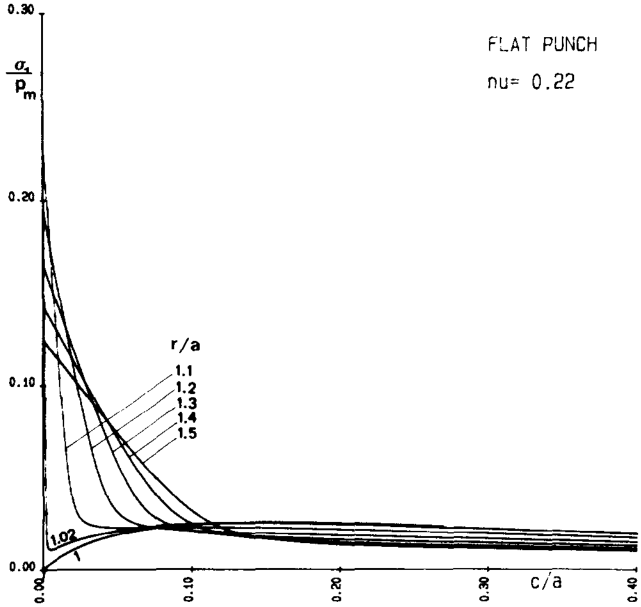

Figure 2. The distribution of principal stress for different r/a values.

with

$$\left[\phi\left(\frac{c}{a}\right)\right]_{r/a} = \frac{c}{a}\left(\int_{o}^{c/a} \frac{f\left(\frac{b}{a}\right)}{\left(\frac{c^2}{a^2} - \frac{b^2}{a^2}\right)^{\frac{1}{2}}}\, d\left(\frac{b}{a}\right)\right)^2 \quad (4)$$

Figure 3 shows $\phi(c/a)$ for $\nu = 0.22$ and various starting radii r/a. The curves display two maxima for $r/a < 1.25$ and only one for $r/a > 1.25$.

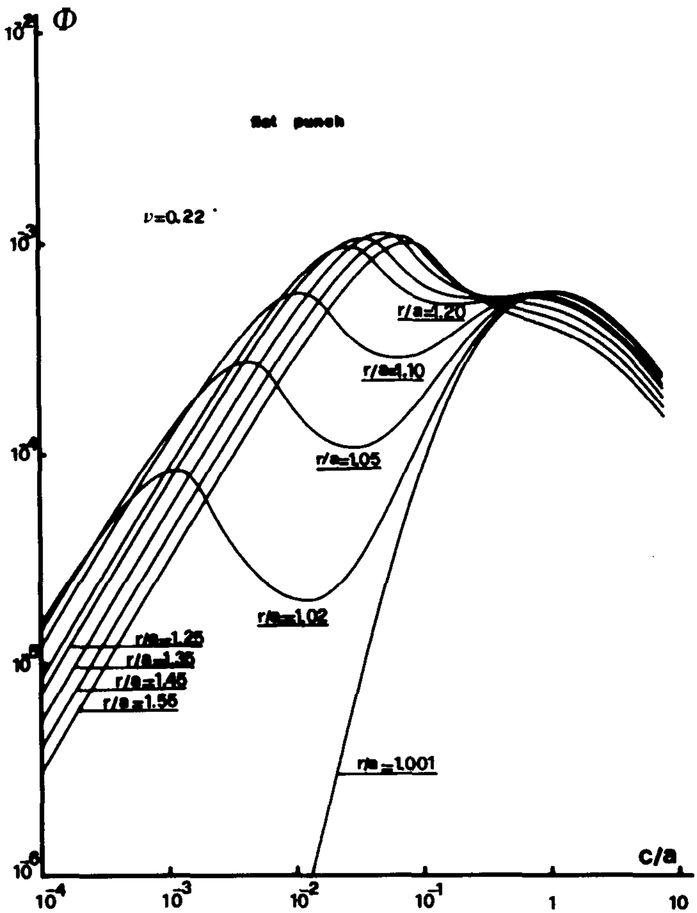

Figure 3. Relationship between $\phi(c/a)$ for various radii r/a and a constant Poisson ratio (0.22).

Consider only the case of curves with a single maximum. Figure 4 shows the variation of $G/2\gamma$ versus c/a at various loads for a flaw situated at r/a = 1.45. Starting with a flaw of reduced length c_f/a and increasing the load, G increases until $G = 2\gamma$ (point A). At this stage, the crack is in unstable