AN EMPIRICAL APPROACH TO THE EVALUATION OF G_{IC} IN CEMENTED CARBIDES BY MEANS OF VICKERS INDENTATIONS

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ABSTRACT

An empirical relationship has been found between the critical strain energy release rate, G_{IC}, of WC-6%Co and parameters obtainable by means of Vickers hardness tests. These results provide a simple method to determine relative values of G_{IC}.

KEYWORDS

Cemented carbides, strain energy release rate, Palmqvist cracks.

INTRODUCTION

Vickers indentation fracture in ceramic materials has been studied extensively as a simple means to determine fracture toughness. Recent work (Anstis and co-workers, 1981) has led to a relationship between fracture toughness, indenting load and length of indentation cracks (usually called Palmqvist cracks) which agrees with experimental results from all the ceramics tested except cemented carbides.

The purpose of the present project was to find experimentally why cemented carbides behave differently from other ceramic materials and to establish if any correlation exists between the toughness of cemented carbides and the parameters obtainable from Vickers hardness tests.

METHOD AND RESULTS

A WC-6%Co sample was polished according to the method suggested by Exner (1969) and indented by means of a standard Vickers indenter (apex angle = 136°) at the following indenting loads: 50, 100, 150, 200, 250, 300, 350, 400, 500, 600 N. Five indentations were made at each load. After measuring the length of the diagonals of the indentations and the length of the Palmqvist cracks (the measurements being taken by optical microscopy at ∿ 500 X magnification), the specimen was repolished using 3 μm diamond powder for about 30 minutes and 1/4 μm diamond powder for about 10 minutes. This process removed a ± 10 μm thick layer of material from the indented surface.

The depth of the layer removed was measured from the decrease in length of the diagonals of the indentations. After measuring the new length of the Palmqvist cracks, another ± 10 μm layer of material was removed and the measurements repeated. The process was continued until all traces of Palmqvist cracks had disappeared from the surface. These measurements made it possible to draw the average area of the Palmqvist cracks at each load (Fig. 1 shows a typical crack) and to measure it. The results are reported in the following table.

TABLE Indenting loads used in the experiments, average length and average areas of the Palmqvist cracks obtained at each load

Indenting load (N)	Average length of one crack (m)	Average area of one crack (m^2)
50	1.5 10^{-5}	1.1 10^{-11}
100	3.2 "	2.1 10^{-10}
150	5.4 "	7.8 "
200	7.3 "	1.4 10^{-9}
250	8.8 "	2.6 "
300	1.1 10^{-4}	3.6 "
350	1.2 "	5.6 "
400	1.4 "	7.7 "
500	1.6 "	1.2 10^{-8}
600	2.0 "	1.9 "

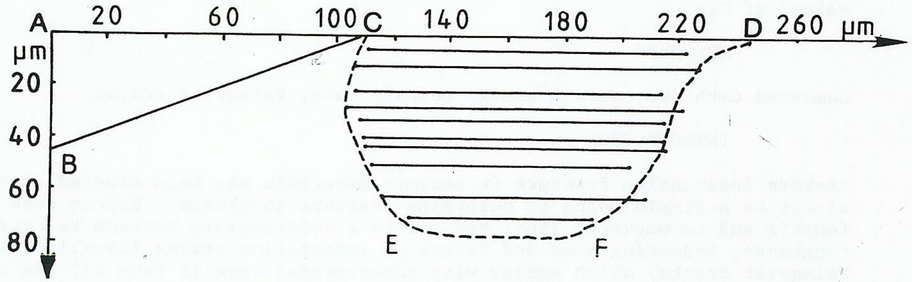

Fig. 1. Area of a typical Palmqvist crack (indenting load = 400 N). AB is the depth of the Vickers indentation, AC the length of half of the diagonal of the indentation, CD the original length of the Palmqvist crack. Each horizontal line within the area of the crack represents the length of the crack measured after each repolishing of the sample. The last measurement is represented by EF, after having removed ∿ 70 μm of material. The sources of error in the evaluation of the area of the crack are evident from this picture. The error has been estimated as being ∿< 5%.

The average area, A, of the Palmqvist cracks at each indenting load was plotted against the average length ℓ of the cracks (Fig. 2). A linear relationship was found to exist between log A and log ℓ (correlation coefficient

= 0.998) and by regression analysis it was found that:

$$A = K_1 \ \ell^{2.5} \qquad [1]$$

where $K_1 = 3.3\ 10^{-5}\ m^{-\frac{1}{2}}$ for the material tested.

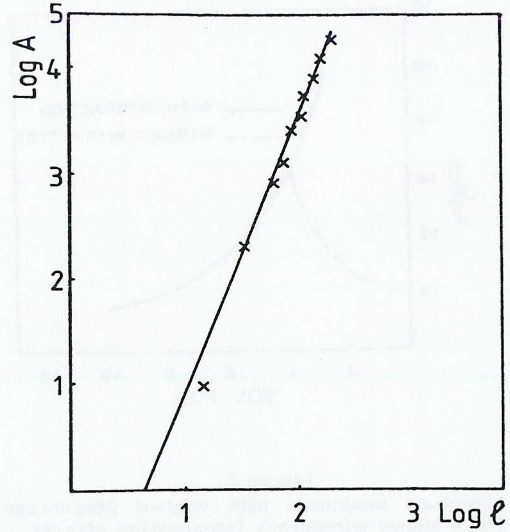

Fig. 2. Relationship between the average area, A, of the Palmqvist cracks and the average length, ℓ, of the same cracks at the indenting loads listed in the Table.

The dimensions of K_1 suggest that K_1 is a material-dependent constant related to the properties which control the deformation and fracture behaviour of the material, namely to the ratio H/K_{IC}, where H is the hardness and K_{IC} the fracture toughness. For reasons that will appear from the rest of the paper we assume K_1 to be proportional to the inverse of the square root of a critical length, d_o, corresponding to the indentation diagonal at which cracks are first formed. Therefore we rewrite [1] as

$$A = \frac{\alpha}{\sqrt{d_o}} \ \ell^{2.5} \qquad [2]$$

where α is a dimensionless constant.

The work done in producing a Vickers indentation was calculated (see Appendix) as being

$$W = \beta \ P \ d \qquad [3]$$

where P is the indenting load, d the diagonal of the indentation and β a dimensionless constant equal to 3.7 10^{-2}.

Since the Palmqvist cracks were found to be the only cracks nucleated by the indentations, the fraction of the total energy which was expended in fracture can be expressed as:

$$f_p = \frac{G_{IC}\ \Sigma A}{\beta P d} \qquad [4]$$

where G_{IC} is the critical strain energy release rate of the material tested. ΣA is equal to 4A, i.e. the sum of the areas of the four Palmqvist cracks around each indentation.

f_p/G_{IC}, i.e. $\frac{\Sigma A}{\beta P d}$, was plotted against $\sqrt{d}$ (Fig. 3) and a reasonably linear relationship was found to exist (correlation coefficient = 0.981).

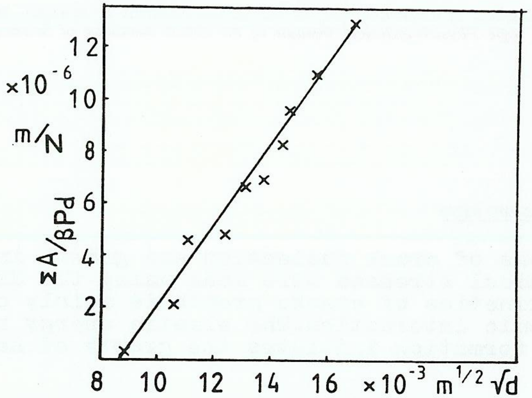

Fig. 3. Relationship between the normalized energy expended in fracture during a Vickers indentation and the square root of the diagonal of the indentation.

Since G_{IC} is a constant of the material, the following relationship must also exist:

$$\frac{G_{IC}\ \Sigma A}{\beta P d} = K_2 \sqrt{d} - \gamma \qquad [5]$$

where K_2 is a constant having dimensions $[L]^{-\frac{1}{2}}$ while γ is a dimensionless constant. Since no fracture occurs for $d \leq d_o$, it can be stated that:

$$K_2 \sqrt{d_o} = \gamma \qquad [6]$$

Therefore:

$$\frac{G_{IC}\ \Sigma A}{\beta P d} = \frac{\gamma}{\sqrt{d_o}} (\sqrt{d} - \sqrt{d_o}) \qquad [7]$$

Combining [2] and [7] one obtains:

$$G_{IC} = \frac{\beta \gamma P d}{4 \alpha \ell^{2.5}} (\sqrt{d} - \sqrt{d_o}) \qquad [8]$$

where $\frac{\beta\gamma}{4\alpha}$ is a dimensionless constant.

From [8] it follows that

$$G_{IC} \propto \frac{P\ d^{1.5}}{\ell^{2.5}} \qquad [9]$$

where P, d and ℓ are all obtainable from Vickers hardness tests.

CONCLUSION

Relationship [9] indicates that relative values of the critical strain energy release rate of cemented carbides can be obtained by measuring the length of the diagonals of indentations produced at a given load and the length of the corresponding cracks, nucleated at the corners of the indentations.

The difference between the present results and the results obtained by Anstis and co-workers (1981) for ceramics is due to the different geometry of the Palmqvist cracks in the two materials. In ceramics the cracks can be considered as semicircular and so $A \propto \ell^2$, while in WC-Co the cracks have a more complex shape and $A \propto \ell^{2.5}$.

Work is in progress to find the constants in [8] by independent determinations of G_{IC} and to control if [8] is valid for all cemented carbide grades.

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APPENDIX

The total work done when a load P is applied to produce a Vickers hardness impression having diagonal d was calculated as follows (see Öhman and co-workers, 1967). The work required to produce an impression of depth h is

$$W = \int_0^h P\, dh$$

but from the definition of Vickers hardness, H_V, $P = \frac{H_V\ d^2}{1.85}$

and $h = \frac{\frac{1}{2}d}{tg\ 68°} = 0.2\ d$, for the standard Vickers indenter used.

As a result:

$$W = \int_0^d \frac{H_V\ d^2}{1.85}\ 0.2\ dd = \frac{0.2\ d^3\ H_V}{3 \times 1.85} = 3.7\ 10^{-2}\ P\ d.$$