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USING OF INDENTANT TECHNIQUES TO DETERMINATION OF CERAMIC MATERIALS  
MECHANICAL PROPERTIES

VYUŽITÍ INTENDANČNÍCH TECHNIK K URČOVÁNÍ MECHANICKÝCH VLASTNOSTÍ  
KERAMICKÝCH MATERIÁLŮ

**Abstract**

Indentant technology is using for classification of mechanical quality ceramic materials in relatively wide measurement. Using indentant methods, which was a long life to use for classification hardness of different type materials, was recently broadened to determination broken tenacity  $K_{IC}$ , broken energy  $\gamma_F$  in normal and temperature rise, creep behavior, fatigue responses and next important quality of ceramic materials. This article is dealing with method and calculation of determination broken tenacity  $K_{IC}$

**Abstrakt**

Intendanční technika je používána k hodnocení mechanických vlastností keramických materiálů v poměrně široké míře, což souvisí s rozvojem poznatků o mechanismu odezvy těchto materiálů na tento typ mechanického zatěžování. Použití intendančních technik, které se dlouhou dobu používaly k hodnocení tvrdosti různých typů materiálů, se nedávno rozšířilo o určování lomové houževnatosti  $K_{IC}$ , lomové energie  $\gamma_F$  za normálních i zvýšených teplot, creepového chování, únavové odezvy a dalších důležitých vlastností keramických materiálů [2]. Tento článek se konkrétně zabývá metodami a výpočty určení lomové houževnatosti.

## 1 INTRODUCTION

Hardness measuring is the most widely used methods to ceramic material properties verify, because we can operatively defined relevant data. Measured values help to characterized stability at broad spectrum of ceramic's fortress.

Hardness is one of critical property for cutting tools, moulds, joints, and others machinery which is effort by abrasive wear.

Measured was at impact hammer by Knoop or Vickers type by means of diamond edge. These equipments do indentation and their diagonal is measured by the optical microscope. For hardness measuring is usually using techniques by Vickers, Knoop, Berchovich (triangular pyramid). Rockwel and Brinel methods are using seldom.

High account of indentant techniques is use of common equipment at many laboratories, obtain big statistical file at small samples, for example cutting insert and simplicity of measuring.

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Fracture toughness is characterizing limiting values of broken tenacity  $K_{IC}$ . It is serves to determination of resistance to failure. Knowledge of fracture toughness makes it possible to evaluate stability against failure [1].

## 2 INDENTANT CLASSIFICATION BY HERTZIAN

Indentant by Hertzian is car IndentantT classification ry on by ball indenters. Radius is usually  $R = 1\div 10\text{mm}$ . At critical load  $P_c$  (defined like 50% load, when indentant call crack), rising roundness cracks, which are bellow the surface of testing material and spreads in conical shape. At *fig. 1* is schematic material cross section at using Hertzian techniques.

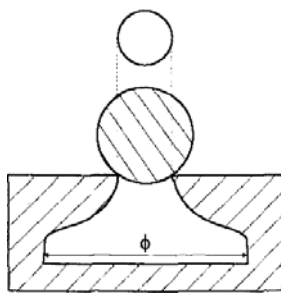
At Hertzian's indentant methods is contact surface between ball and sample given by equation:

$$a = \left( \frac{4kPR}{3E} \right)^{1/3} \quad (1)$$

- $E$  - Young's modulus of elasticity [MPa]
- $R$  - radius of indenter [mm]
- $P$  - applied load [MPa]
- $k$  - dissonance between indenter and equation (2)

$$k = \frac{9}{16} \left[ (1-\nu^2) + (1-\nu'^2) \frac{E}{E'} \right] \quad (2)$$

- $E'$  - corresponding with values for indenter
- $\nu'$  - corresponding with values for indenter
- $\nu$  - Poisson's number



Hertzian's conical crack

**Fig. 1** Cross section during Hertzian's indenter work (top view)

## 3 INDENTANT CLASSIFICATION BY VICKERS

Indentation corpuscle at Vickers techniques is diamond pyramid with top angle  $130^\circ$  and rate of diagonal and depth 1:7. Vickers hardness is determined fro equation:

$$HV = 1,854 \frac{F}{u^2} \quad (3)$$

- $F$  - load force [N]
- $u$  - diameter of diagonal [mm]

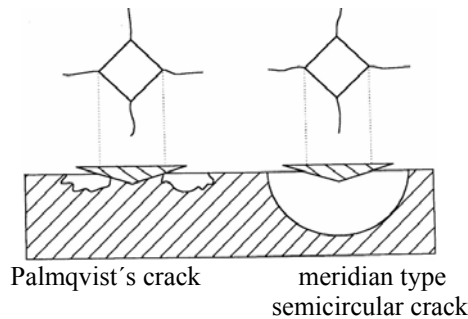
Most widely used method for determination of fracture roughness is indentant method by Vickers. Basic of classification is measuring of Vickers indentation and determination of crack's length around indentation. It is especially in dependence of applied loading, i.e. at corners of indentation.

We prefer sharp Vickers indenter, because have smaller indentation. Cracks around indentation are easy visible and we can easily located edge to testing sample [1].

Vickers indentant techniques precluding to problems joint with crack's creation in contrast at Hertzian methods. In comparison between Hertzian (ball indenter) and Vickers (pyramid indenter) methods happen at Vickers method to permanent indentation. Size of indentation is smaller than at Hertzian and cracks are easily detected.

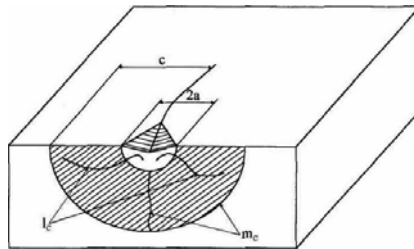
Disadvantage of Vickers methods is different geometry of cracks. Therefore exist many empiric criteria to determinate of fracture roughness  $K_{IC}$ . Schematic views are at figures 2, 3a and 3b [2].

At *fig. 2* are show two indentation types. These two cases corresponding to response after Vickers indenture [1].

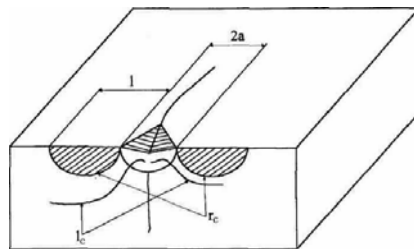


**Fig. 2** Two types of indentant cracks at Vicker's indenter working

At *fig. 3a* and *fig. 3b* are details of indentation at top view and cross section. Figure 3a displays look at median crack  $m_c$  a lateral crack  $l_c$ . At figure 3b is scheme of radial (Palmqvist) crack  $r_c$  a sub critical lateral crack  $l_c$ .



**Fig. 3a** Scheme of initial cracks at Vickers indent,  $m_c$  - median crack,  $l_c$  – lateral subsurface crack,  $a$  – diagonal of Vickers indent



**Fig. 3b** Scheme of initial cracks at Vickers indent,  $l_c$  – lateral subsurface crack,  $r_c$  – Palmqvists crack,  $a$  – diagonal of Vickers indent

Creation of Palmqvistova crack is note at lower indentant load. On the contrary meridian (radial) type is at higher load of indenter. To determine of fracture roughness was suggested several equations (*Table 1*). Some of equations are reaching to Palmqvist cracks and others to meridian cracks. Any are restricted by type of material.

#### 4 INDENTANT CLASSIFICATION BY KNOOP

Knoops indentant is less using to classification of fracture roughness  $K_{IC}$  than Hertzians or Vickers. Surface cracks are usually obscure at indention corners and lateral cracks are at both side of indentation initial.

Knoops indenters are diamond pyramid with ratio long and short diagonal  $a/b = 1:7$ . Angle at long diagonal is  $172^\circ 30'$  and at short diagonal  $13^\circ$ . Hardness by Knoop is according equation:

$$HK = 14,50 \frac{F}{a^2} \quad (3)$$

$F$  - load force [N]

$A$  - longer diagonal [mm]

Hardness measured by Knoop is time consuming and is orienting to surface opposite of Vickers indentation by the same load. Advantage is using higher load force without chipped of ceramic material [1].

**Tab. 1** Empirical equations proposed to determination of fracture roughness  $K_{IC}$  ceramic materials by Vickers indentant techniques

Fracture roughness KIC [MPa.m <sup>1/2</sup> ]	Authors
$K_{IC} = 0,1704Ha^{1/2} \log\left(4,5 \frac{a}{c}\right)$	Evans & Wilshaw [3]
$K_{IC} = 0,057Ha^{1/2} \left(\frac{E}{H}\right)^{2/5} \left(\frac{c}{a}\right)^{-3/2}$	Svand, et al. [7,9]
$K_{IC} = 0,0303Ha^{1/2} \left(\frac{E}{H}\right)^{2/5} \log\left(8,4 \frac{a}{c}\right)$	Blendel [4]
$K_{IC} = 0,0139Ha^{1/2} \left(\frac{E}{H}\right)^{2/5} Pc^{-3/2}$	Lawn, et al. [6]
$K_{IC} = 0,016 \left(\frac{E}{H}\right)^{1/2} Pc^{-3/2}$	Anstis, et al. [5]
$K_{IC} = 0,071Ha^{1/2} (EH)^{2/5} \left(\frac{c}{a}\right)^{-3/2}$ <i>for</i> $\frac{c}{a} > 2,5$	Niihara, et al.[7]
$K_{IC} = 0,0139Ha^{1/2} \left(\frac{E}{H}\right)^{2/5} \left(\frac{c-a}{a}\right)^{-1/2}$ <i>for</i> $1,25 < \frac{c}{a} < 3,5$	Niihara, et al.[7]

$K_{IC} = 0,0782Ha^{1/2} \left(\frac{E}{H}\right)^{2/5} \left(\frac{c}{a}\right)^{-1,56}$	Lankford [6]
$K_{IC} = 0,098 \left(\frac{E}{H}\right)^{2/3} Pc^{-3/2}$	Laugier [8]
$K_{IC} = 0,035 \left(\frac{E}{H}\right)^{1/4} Pc^{-3/2}$	Tahala [9]
$K_{IC} = 0,015 \left(\frac{E}{H}\right)^{2/3} \left(\frac{c-a}{a}\right)^{-1/2} Pc^{-3/2}$	Laugier [10]
$K_{IC} = 0,055 a' Hd^{1/2} \left(\frac{E}{H}\right)^{2/5} \left(\frac{c}{a}\right)^{\left(\frac{c}{18a} - 1,51\right)}$ <p>where <math>a' = \frac{1}{\left[14 \left(1 - 8 \frac{4\nu - 0,5}{1 + \nu}\right)^{0,4}\right]}</math></p>	Liang, et al. [3]

where

- E - Young's modulus of elasticity [MPa]
- H - hardness [MPa]
- P - applied load
- a - half of Vickers diagonal [mm]
- c - length of crack measured from centre [mm]
- $\nu$  - Poisson's number

## 5 CONCLUSIONs

Next research and application of these methods can engineer to quicker testing of ceramic cutting tool inserts. Especially compare results at tool life testing and indentant techniques.

Context match between indentant techniques and cutting tool tests during machining is target of dissertation and diploma thesis at department of machining and assembly and cooperation work-places not only from Technical University of Ostrava.

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