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ANALYSIS OF STRESSES AND DEFORMATIONS AT AN EVALUATION OF MICROHARDNESS AND SURFACE TOUGHNESS

ANALÝZA NAPJATOSTI A DEFORMACÍ PŘI HODNOCENÍ MIKROTVRDOSTI A POVRCHOVÉ HOUŽEVNATOSTI

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Abstract

Hardness testing is a method frequently used for evaluating the resistance of body surfaces to the influence of contact loading. The Vickers hardness test is applied for this purpose in a case when the material is sufficiently ductile and no cracks occur in the corners of the indents. Testing of the surface hardness of such materials as glass and ceramics on the basis of the Vickers testing method must take into account the energy that is spent on crack spreading. This paper describes a more exact and accurate method for evaluating resistance to microcrack formation on the surface of a material. To evaluate the conditions for crack spreading, it is necessary to test a specimen under loading in bulk. The suggested procedure involves a bent strip. As bending stresses are known, from them and from the differences in crack length along and across the strip, the resistance of the material surface to crack propagation is determined.

Keywords : hardness, toughness, indent, testing, method

Abstrakt

Zkouška tvrdosti je metoda používaná k hodnocení odporu povrchu materiálů proti účinkům kontaktního namáhání. Velmi široký obor materiálů vykazuje v širokém rozsahu zatížení mechanické vlastnosti kontrolované plastickou deformací. Vznik trhlin vycházejících z vrcholů vtisku pak vykazují povrchy a tenké vrstvy z některých vysoce tvrdých materiálů. Pro hodnocení odporu materiálu proti vzniku a šíření povrchových mikrotrhlin byla navržena a odzkoušena nová metoda stanovení této materiálové charakteristiky. Metoda spočívá v provedení Vickersova vtisku do vzorku namáhaného ohybem tak, aby hrany vtisku byly orientovány podél a napříč vzorku. Jelikož ohybové napětí přispívá k rozšíření příčné trhliny, dává podíl vloženého ohybového napětí k rozdílu délek příčné a podélné trhliny, požadovanou informaci. Příspěvek se zabývá testováním této metody na vzorcích z povrchově upraveného float skla.a seznamuje s dosavadními výsledky.

Klíčová slova: tvrdost, houževnatost, vtisk, zkoušení, metoda

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1. Introduction

Hardness testing with the use of Vickers, Knopp or Berkovich indent tip methods was frequently employed in the past for estimating the resistance of material surfaces to damage caused by a contact load. Indent techniques are applied today to characterise material properties in a more general sense. The indent process therefore needs to be analysed. Two comprehensive reviews from this field have been presented recently. The paper of Larson and Giannakopoulos [1] deals with the application of indent methods for an estimation of the properties of so-called pressure-sensitive hard metals and ceramics. In these materials, instead of indents, cracks occur in their vicinity. Ericson et al [2] analyse the strain field and residual stresses around the indents in both brittle and ductile materials. The overall picture of the indents needs to be supplemented by partial or a full recovery of indents for materials such as epoxides and alkamides, which hold information about elastic properties.

When indent methods are applied for characterising materials, it is necessary to take into account that bulk material properties and quantities, such as modulus of elasticity, yield stress and critical stress intensity factor, are defined at a homogeneous stress state of the material macrovolume. A decomposition of the indent object, which is strongly local and non-homogeneous, into the individual damage components, is the main problem in estimating the hardness quantity. The hardness quantity derived on this basis is always conventional. The surface properties can be classified exactly by a combination of the indent method and external loading, which is chosen in such a way as to cause a state of homogeneous stress on the specimen surface, which is superposed with the stress state caused by the indent [3]. This technique was verified by estimating material surface resistance to cracking initiated by an indent.

2. Experimental analysis

Hardness testing is the method mainly used by metallography and by strength of materials. Its initial purpose was a determination of comparative magnitudes of mechanical properties of materials surfaces. Different kinds of indent tips are applied, namely Vickers, Knoop, Rockwell, Brinell. Their common characteristic quantity is a nonhomogeneous strain and stress field around them and only hardness values of indents with a similar strain and stress fields are comparable. An analysis of the strain field around the indent is necessary. Next two images show an irreversible deformation around the indent and brittle fracture along the indent diagonal.

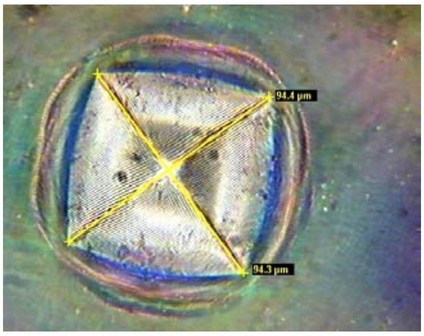

Fig.1 The deformation around the Vicker's indent done into a polymer layer with Moiré grid 1200 lines /mm. Image – optical microscop ZEISS Amplival with CCD kamera JAI(768x576 pixels)

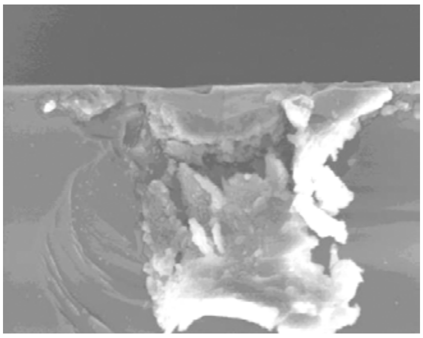

Fig.2 The Si plate with the brittle fracture going along Vicker's indent diagonal. Image-SEM Tesla BS 340, magnification 10000x. Digital rekord TESCAN WinTip (512x512 pixels)

2.1 Toughness testing

The testing of surface mechanical properties of such materials as glass and ceramics, using the Vickers method, must take into account crack formation in the indent corners. A quantitative estimation, based on the Vickers testing method, must take into account the energy spent on crack spreading. The area marked by the crack tips around the indent are deformed by the indent elastically, and it is from here, that this energy is released. The mean intensity of the indent force over this area thus characterizes a surface property of a material, similar to its hardness, which can be named toughness T_v.

The Vicker's toughness /T_V/ of the float glass plate surface with evaporated metal layer given below /Tab.1/ are calculated from the formula $T_v = 1{,}89096e5 * F / D_c^2$.

Load F(N)	T_v x10^7MPa	T_v x10^7MPa
	$\Delta\sigma_1$=14,66MPa	$\Delta\sigma_2$=21,99MPa
1	13,1	16,8
1,5	12,8	13,1
2	11,7	2.1

Table 1. Vicker's toughness values of the float glass plate with metal layer

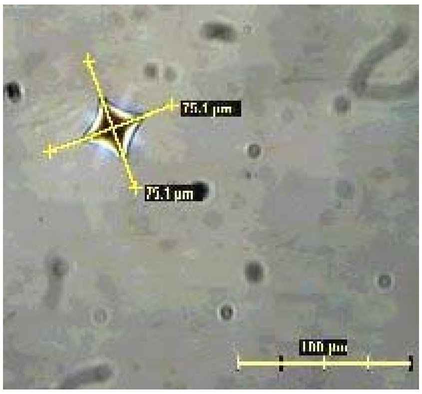

Fig. 3 The image of an indent with measured length of cracks. Optical microscop ZEISS Neophot 21 with CCD camera JAI(768x576 pixels)

2.2 Surface crack toughness testing

The indent method is still used for evaluating the material properties of samples in bulk free of loading. A more exact and more accurate method for evaluating the resistance of a material surface to the growth of microcracks is derived from techniques used for testing fracture toughness. To evaluate the conditions for crack propagation, it is necessary to test the specimen under loading. The suggested procedure involves a bent strip. The Vickers indents are carried out in such a way that the edges of the indent pyramid are oriented parallel and orthogonally to the strip length. When the indent is now made, the bending stresses cause cracks that are orthogonal to the strip length to be bigger. As bending stresses are known, from them and from the difference in the crack lengths along and across the strip, the resistance to the propagation of cracks in the material surface can be determined. The difference between macro and micro toughness testing depends on whether the stress state that causes crack propagation is present in the material before or after the moment when the crack originates. The problem of a Vickers indent with cracks in its corners will be described on the basis of the crack problem by stress intensity factor $K_{I,}$ which is expressed by the formula [4].

$$K_I = f\left(\frac{c}{a}\right)\sigma\sqrt{\pi l} \tag{1}$$

The change of the stress intensity factor K_I due to the bending of the specimen is obtained from the differentiation of the foregoing expression

$$\frac{\Delta K_I}{\Delta l} = \frac{\Delta\sigma}{\Delta l}\sqrt{\pi l}\,F(l) + \frac{\sigma}{2}\sqrt{\frac{\pi}{l}}\,F(l) + \sigma\sqrt{\pi l}\,\frac{\Delta F(l)}{\Delta l} = \mathit{const} \tag{2}$$

which, after arrangement assuming initial conditions $\sigma = 0$, $\Delta l = 0$, $\Delta F(l) = 0$, obtain for a determination of the toughness of the surface crack the form

$$\frac{\Delta K_I}{\Delta l} = \frac{\Delta\sigma}{\Delta l}\sqrt{\pi l}\,F(l) \tag{3}$$

2.3 The evaluation of the surface crack toughness of the float glass plate

The evaluation of the surface crack toughness of the float glass plate was carried out on a bar specimen having length 145mm, width 11mm and thickness 8mm. A bending of the specimen is realized by a loading device, which schematic drawing is given bellow /Fig.4/. The specimen is now bent by the load P, for which were chosen two magnitudes 20 and 30 N. The bending stress σ is now calculated from the formula

$$\sigma = \frac{M}{W} = \frac{M \text{ is the bending moment in the place of central support according to the loading scheme}}{W \text{ is the cross section characteristic - 1/6width x thickness}^2}$$

and its values are introduced in the table /Tab.2/.

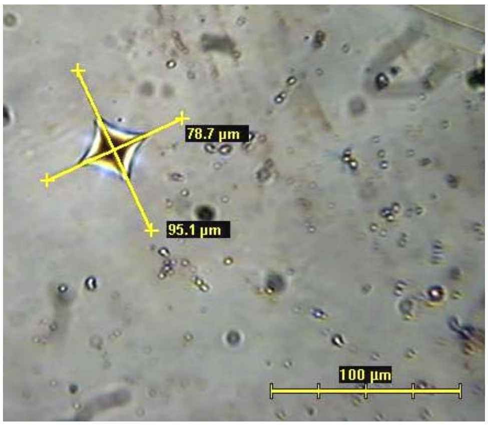

Fig.5 The image of indent in the bent specimen with measured length of diagonals. Optical microscop ZEISS Neophot 21 with CCD camera JAI(768x576 pixels)

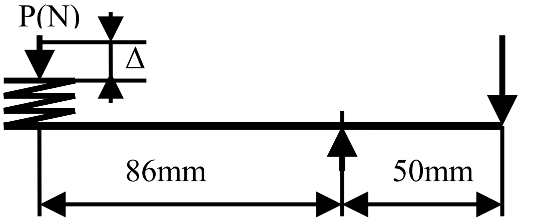

Fig.4 The schematic drawing of the bending device and the loading diagram.

Load F(N)	ΔK/Δl x10^7N/m$^{5/2}$	Δl x10^{-6}m	ΔK/Δl x10^7N/m$^{5/2}$	Δl x10^{-6}m
	$\Delta\sigma_1$=14,66MPa		$\Delta\sigma_2$=21,99MPa	
1	3544	4,8	2064	13,1
1,5	2084	9.4	1364	23,8
2	1017	22,8	1247	29,1

Table 2. The surface crack toughness values of the float glass plate with metal layer.

The next image shows one from indents worked out into a bent specimen /Fig.4/. They are carried out by the three magnitudes of the indent force F. The differences Δl between transversal and Longitudinal crack, measured from images, are introduced commonly with indent force F in the table /Tab.2/. The magnitudes of the resulting values of the surface crack toughness, calculated from Eq. (3) are given at the same place.

3. Conclusions

This paper is dealing with a resistance of a float glass surface against growth of microcracks. To Two approaches are discussed. The first, named hardness testing, proposes to evaluate the resistance of a material surface by a local indent test. The latter technique, toughness testing, proposes to evaluate a material surface resistance to crack propagation by crack toughness testing. The technique needs further improvement as in experimental hardware so in software. Both technics show dependence from external load and stress intensity function F(c/a), see Eq. (1) and further improvement as in experimental hardware so in software.

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