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Unified curve of the edge chipping resistance in connection with the rounding radius indenter

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ABSTRACT

The results of a combined computational and experimental research into the fracture resistance of ceramic materials by specimen edge chipping are provided. The chipping was performed with conic diamond indenters that had spherical tip radii of 100, 200 and 400 μm. The computational analysis was conducted on the basis of finite element modeling by means of ANSYS software. The parameters of the basic distances in an analysis of the stress, strain, and displacement fields in the chipping zone for the tests (upper and lower limit) have been established for the above-mentioned indenters in order to ensure the correct comparative assessment of the materials under research. Unified curves of edge chipping resistance of the ceramic materials have been obtained for the indenters with various spherical tip radii.

1. Introduction

The method of chipping the specimen's rectangular edge with indenters [1–12] is used when determining the fracture resistance of structural, functional, biomedical ceramics, glass, and other brittle materials. The fact that it unites the processes of appearance of the surface cracks and their further development that leads to formation of the chip should be mentioned as an advantage of the method. This gives every reason to rate it as rather promising for researches into materials' properties. However, substantially varying experimental methods and different fracturing tools are applied during specimen edge chipping tests at present. Different researchers use specimens of various shapes and sizes for the tests. Little attention is paid to the indenter's position relative to the edge of the tested specimen. As a result of this, the experiment results obtained by the different researchers turn out to be hardly comparable. An empirical approach prevails in the researches of brittle materials' fracture resistance through specimen edge chipping.

The authors of this paper apply a combined computational and experimental approach to a research into fracture resistance of brittle materials through specimen edge chipping. The computational research was performed on the basis of finite element modeling by ANSYS software. The stress-strain state of specimens made from silicon nitride, aluminum oxide and zirconium dioxide ceramics in the zone of the contact with the indenter at various distances from the specimen edge was analyzed [13–15]. The paper provides the data of the edge chipping experiments on specimens made from silicon nitride and zirconium dioxide using conic diamond indenters with spherical tip radii of 100, 200, and 400 μm as well as the results of the computational research into influence of the tip radius on the specimens' stress-strain state and fracture resistance.

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Nomenclature

a	radius of the contact surface boundary
d	distance from the center of the indenter to the edge of the specimen
L	distance from the edge of the specimen to the extreme point of the chip
P_f	fracture load
R	tip radius of the indenter
X, Y, Z	coordinate axes
E	elastic modulus
ν	Poisson's ratio
U_x, U_y, U_z	components of the displacement vector U
$\varepsilon_1, \varepsilon_2, \varepsilon_3$	principal strains
$\sigma_1, \sigma_2, \sigma_3$	principal stresses
K	similarity coefficient

The computational analysis and interpretation of the experiments were conducted taking into account geometric similarity conditions. The analysis was pointed out to search possibilities of comparison of the results of testing one material with various indenters and for comparison of the results of testing various materials.

2. The methods of the experiment and the materials

The experiments of this work were performed with the application of specimen edge chipping tests, the procedure of which is set forth in [1–3]. The test procedure consisted in chipping the edges of specimens polished to a mirror finish. The specimens used in the experiments were rectangular beams with a cross-section of 3000 μm × 4000 μm. The edges were fractured with conic diamond indenters that had various radiuses of their spherical tips (R = 100, 200 and 400 μm) manufactured on request and calibrated in Gilmore Diamond Tools, Inc. (USA). The indentation speed was constant and equal to 5 mm/min. During the tests, the load was applied in the direction perpendicular to the surface of the specimens with a width of 3000 μm. The fracture load P_f was registered by a computer. Then, using a BX51 M Olympus (50–1000×) microscope and the program QuickPhoto Micro 2.3, the chip that formed at the edges of the tested specimens were photographed and analyzed. A specimen of the silicon nitride ceramic and chip in the formative stage is given in Fig. 1. Here, L is distance from the edge of the specimen to the extreme point of the chip, d is distance from the center of the indenter to the edge of the specimen. Ceramics based on silicon nitride ($E = 2.5 \times 10^{11}$ Pa, $\nu = 0.24$) and zirconium dioxide ($E = 2.11 \times 10^{11}$ Pa, $\nu = 0.23$) were used as the experimental materials.

3. Numerical simulation of tests

The finite element modeling and computational analysis of edge-chipping test data for brittle materials were performed with the help of ANSYS software. A static three-dimensional nonlinear contact problem about impressing conic diamond indenters with various tip radii (R = 100, 200 and 400 μm) into a specimen was solved. During the calculations, the distance d from the specimen surface indentation center to the specimen edge (Fig. 1b) and the respective experimental values of the fracture load P_f were varied. The model was built for the active part of the indenter and the fragment picked out of the specimen. By reasons of symmetry about the plane YZ, half of the model was analyzed. Fig. 2 represents the finite element model taken for the calculation. The solid (specimen) was divided into SOLID 185 finite elements. The model of an elastically solid was used for the researched materials (ceramics based on silicon nitride and zirconium dioxide). The same moduli of elasticity were taken for the tension and compression, which conforms to their relevant properties. Effects of the friction were not taken into account when solving the contact problem. The surface-to-surface contact was assumed to be rigid-to-flexible. The target surface (indenter) was considered to be rigid and have a pilot (leading) node using which the boundary conditions and the target surface movement were managed. The boundary conditions (of displacement and load) were attached to the pilot node. The interacting parts of the model were covered with the contact elements. The finite 3-D element TARGE 170 was chosen for the target surface. The contact surface with the 3-D contact element CONTA 174 was located on the surface of the specimen. Then the rigid-to-flexible contact pair was created. Details of the numerical procedure are given in Ref. [14]. In order to perform a more detailed research of the obtained calculation results, the menu item Path Operations was used in the software postprocessor, which is designed for analyzing changes of the functions along the chosen paths. As part of this operation, various paths (PATH *Si*) were built along which changes of the components of the displacement vector together with the strain and stress tensors were investigated.

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