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Development of Indentation Method for Evaluating the Effectiveness of Machining of Ceramic Parts

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Abstract: The purpose of this investigation is to study the influence of the state of the ceramic surface after grinding and laser machining on number and length of the cracks as well as size of local fracture area formed during indentation by a diamond cone. Revealed relationships allowed to adapt the indentation method for evaluating the effectiveness of different technological methods of ceramic parts processing.

Keywords: Ceramic; Surface; Machining; Indentation; Crack; Fracture.

1 Introduction

Indentation method is widely used when studying strength properties of ceramics and nature of their fracture [1]. This method is based on the study of the ceramic surface and detecting the cracks formed in the vicinity of the diamond indenter pressed into the surface of the sample with a specific load. However, obtaining the objective experimental data and subsequent comparison of the calculated coefficients for different materials requires a necessity to use ceramic samples with the same morphology [2]. This is due to the fact that the state of surface layer of the samples has a significant impact on its stress-strain state formed by the action of power load [3]. The objective of this research is to study effects of the state of ceramic surface after grinding and laser machining by number and length of cracks as well as area of local fracture zones during indentation of diamond indenter and on this base to adapt the indentation method for evaluating the effectiveness of different technological methods of processing of ceramic parts.

2 Experimental Procedure

The samples of ceramic system Al_2O_3–TiC after grinding and pulse laser machining were researched. Grinding was done on a machine OSH-440 with using a coolant [4]. Laser machining of the ceramic samples was carried out on a process unit U-15, equipped with solid state source Nd:YVO_4 with diode pumping [5]. The experiments on indentation of sample surfaces were performed on hardness tester using a diamond indenter of conical shape. Optical microscope, SEM and profilometer were used for study of the state of the ceramic surface after machining. The state of ceramic samples surface after the indentation was evaluated by diameter of indenter imprint, number and average length of radial and lateral cracks, area of local fracture zones.

3 Results and Discussion

It was found that in the result of indentation of the radiused shape cone, a spherical imprint-dimple with clear boundary is formed on the surface, where the diameter of this imprint proportionally depends on the applied load. The surface morphology of the undamaged spherical dimple bottom has visible traces of plastic deformation. In case of partial or complete fracture of the dimple bottom surface, it can be seen that cleavage of ceramics occurred by a brittle mechanism. On the interface of the spherical hole with the processed surface of the ceramic formed numerous arc cracks, which initiate the formation and growth of radial cracks. Very often, the source of origin for radial cracks is intersection of arc crack with technological defect formed on the ceramic surface when grinding. Radial cracks grow in opposite directions from the dimple's boundary, and under action of small load on the indenter, growth of these cracks is stopped without reaching the surface. In case of indentation of the cone into a ceramic sample with average load, radial cracks grow into the interior volume of the ceramics along the path practically parallel to the surface, and the depth of penetration does not exceed 0.05 mm. At a distance $l = 2 \div 3\ D_o$, radial cracks break the surface and form lateral cracks. These cracks have the appearance of broken line and their length is limited to the points of intersection with radial cracks. However, in this case radial cracks do not have enough energy for mutual merger. Only during indentation of the cone with large load, energy for merger of adjacent radial cracks in the ceramic surface is enough. The next phase is the local fracture of the ceramic surface fragment in the form of characteristic ”flake”.

The number of cracks and the size of local fracture during indentation increase proportionally to the level of intensification of grinding regimes. At the same time, area of fracture ceramic fragments and damaged surface area of the spherical dimple increase significantly. It was found that the nature of the ceramic surface fracture after laser machining does not change, but regimes of laser machining have impact on the number and the size of cracks, as well as local fracture area. After laser machining on the minimum regime, fracture area is limited by two radial cracks and one edge crack, in this case a dimple surface does not break. Laser machining on the medium regime initiates fracture of a larger area of ceramics during indentation. In this case several zones of fracture are formed around the dimple bounded by two radial cracks and one later crack. During indentation of the surface processed on the maximum regime, there is a complete fracture of the dimple surface, and radial and edge cracks are combined to form a closed area of fracture. The depth of the damaged surface layer reaches the size of 0.2 mm. It can be seen (1) that the measurement results obtained using the indentation method correlates with the state of the ceramic surface layer and (2) increase of the applied load leads to the increase in the average length of radial cracks, and imprint diameter and local fracture area. To the greatest extent, this fact appears during indentation with load $F = 60$ kg.

4 Conclusion

These studies revealed relationship of the state of ceramic surface after grinding and pulse laser machining with the number and length of cracks, as well as local fracture area after indentation. Essential impact of regimes of these technological processes on the nature of cracks and local fracture formation during indentation of oxide-carbide ceramic surface was disclosed. The analysis of effectiveness of different methods of forming the surface of ceramic parts using the revealed effects was done. Indentation method may be recommended to optimize processing regimes.

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