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Multi-level Method of Stress-Strain State Analysis in Designing of Tools with Ceramic Inserts for Special Applications

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Abstract: The methodological approach to designing of tools with ceramic inserts for special applications based on analysis of their stress-strain state on macrolevel (tool design) and microlevel (ceramic structure) is created. The positive example of application of method in designing and producing of grooving cutter with ceramic inserts is shown.

Keywords: Ceramics; Tool; Insert; Stress-Strain State; Macro- And Microlevels.

1 Introduction

Tools with ceramic cutting inserts of a simple form are widely used in the modern metal working [1]. These inserts have the special geometry that provides the minimization of the stresses in the ceramic surface layer under impact of the operating loads and the decrease in the number of the of the tool failures [2]. However, numerous attempts to create tools with ceramic inserts for special application, for example for groove and thread cutting, had no success due to the lack of a special approach [3]. The goal of this investigation is to develop the methodological approach to the design of cutters with ceramic inserts for special application based on the calculation and analyses of stresses on the two levels.

2 Experimental Procedure

The workpieces of 35KhGSA (*HRC* 48) steel were machined on the different regimes with the use insert RKS22 (ceramic system Si_3N_4+TiC) of the traditional geometry. The wear and local fracture of these inserts were studied with the use of optic microscopes Stereo Discovery V12 Zeiss and SEM VEGA3 LMH. The automated systems "Solid Works" and RKS-ST v.1.0 were used to perform stresses calculations on the macro- and microlevels. The techniques of these numerical experiments are described in details in papers [4, 5].

3 Results and Discussion

The model of the failure of cutter with ceramic insert when groove cutting in the tempered steel was developed in the first stage of this investigation. As the result of the study of the wear of RKS22 inserts at groove cutting, it is determined that the main cause of their failures is the local fracture of ceramics at their two noses that takes place at the width of the flank wear $V_B = 0.2 - 0.3$ mm. The following defects are detected at surfaces of the ceramic fracture: separate discontinuities of the size to 0.1 μm at interfaces of adjacent grains, discontinuity chains at the grain interfaces, cracks in grains and at their interfaces, and pores of different forms and sizes at joints of grains of the main and strengthening phase. Occurrence of these defects initiates the microstresses that are formed at the interfaces of ceramic structural elements (grains of the main and strengthening phase and intergrain phase) under impact of the operating loads. Development and grow of these defects cause chipping and tearing out of separate grains, as well as their conglomerates. On the basis of this model the task of designing tools for specific applications was defined as follows: level macrostresses formed in the noses insert and microstresses formed at interfaces of the ceramic elements of structures under the effect of operational loads must be reduced to a minimum. The solution of this problem was provided by the development of a two-level

method of calculation and analysis of stress-strain state of the tool with ceramic insert using the method of control points.

The macrostresses were studied with the use of a developed 3D-model of a grooving cutter. The influence of the geometry of the ceramic insert on stresses in the noses and cutting end was studied, as well as it was found that the highest stresses were formed in two insert noses. The decrease critical stresses in noses by 15 – 25 % under the following geometrical parameters: the cutting edge inclination λ = +7 °, nose radius r = 0.3 mm and cutting end radius ρ = 30 μm is determined. The results of performed modeling allow to form the input data for the modeling procedure at the microlevel.

A microstructure model of the ceramic fracture under impact of the operating loads was developed and a role of stresses in this process was studied in the second stage of the investigation. The calculation scheme represented as a construction describing the fragment of the surface layer of the ceramic insert and consisting of the grain, intergranular phase and matrix was developed in the second stage. Functional layers (coating) and layer of machined material were located on external surfaces of the base structural elements of the ceramics. The loads (concentrated and distributed forces, as well as heat flows) were applied to the external contour of machined material layer. The effect of the geometry of the grains of the main and strengthening phases, composition of the intergranular phase and structure of the coating layers were studied with the use of this calculation scheme. It is found that the least stresses are formed at the interface of ceramic structural elements in case of the vertical location of the oval grain. The further calculations were performed for this form of the grain. Stresses at grain interfaces of the strengthening phase of TiC and SiC were compared. It is determined that stresses formed at the interfaces of ceramic system TiC–Y_2O_3–Si_3N_4 are less by 17 % than ceramics system SiC–Y_2O_3–Si_3N_4. The effect of properties of the coating layers on the external surface of ceramic structural elements was evaluated, as regards stresses formed at the interfaces in ceramics of the TiC–Y_2O_3–Si_3N_4 under the impact of the combined load was also evaluated. The TiN layer has the best indices in stress reduction. Generalization of the results of the calculations and analysis of stresses in the interfaces allow to develop the scientifically grounded terms of reference for creation of the ceramic material and coating technology that were successfully implemented by specialists in the correspondent technological areas.

4 Conclusion

The methodological approach to the designing of tools with ceramic inserts for special application based on the stress analysis at the macro- (cutter design) and microlevels (ceramic structure) was developed. The new kinds of ceramic inserts with coating were created with using this approach.

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