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# Stress State of Surface Layer of Oxide Ceramics with Single Defect Under the Influence of Intensive Heat Flow

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**Abstract:** The effect of intensive heat flow on stress state of surface layer of oxide ceramics with single defect is studied with the use of the created microstructural model and calculation scheme. The correlation between the heat flow and change character of stresses $\sigma_{11}$, $\sigma_{12}$ and $\sigma_{22}$, as well as stress intensity $\sigma_i$ in the surfaces of the structural elements of oxide ceramics is revealed.

**Keywords:** Ceramics; Stress State; Surface Layer; Single Defect.

## 1 Introduction

The necessity for study the stress-strain state of ceramic parts under the influence of intensive heat flow is of practical importance in connection with the development of new technologies [1]. Various aspects of this problem with the defect-free ceramic surface are viewed in papers [2, 3]. However, the results of these studies are very important for developers of new ceramic compositions, but have limited engineering application. This is due to the fact that the study of models with "ideal" surface does not reflect the realities for modern technologies, which are not capable of producing ceramic parts with a defect-free surface. Surface defects affect the integrity of the system of structurally nonhomogeneous materials and have a negative impact on the stress-strain state and the nature of ceramic fracture, as well as the reliability of these parts. Therefore, the study of the influence of defects on the processes occurring in ceramic surface layer under the influence of intensive heat flow is an actual scientific task. In this paper we set the goal – to investigate the influence of intensive heat flow on the stresses heterogeneity in the surface layer of oxide ceramics with single defect.

## 2 Creating of the Calculation Scheme

The most typical forms of defects in the surface after sintering and grinding were determined in the experimental studies of the surface state of ceramic samples based on alumina made with the use of SEM VEGA3 LMH. One of these defects is a single pore formed by the side surfaces of several neighboring grains (Fig. 1a). The formation of this defect is due to (1) neighboring grains unable to come closer to each other during sintering, and (2) dropping of central grain out from ceramic matrix when diamond grinding. Regarding this defect we developed microstructural model of ceramic surface layer with single defect and then formed the calculation scheme (Fig. 1b). The calculation scheme is presented in the form of construction consisting of the following ceramic structural elements: (1) spherical grain $d$ = 6 μm, (2) intergranular phase $\delta_f$ = 0.2 μm, and (3) matrix. The surfaces on each structural element have been selected wich formed two interfaces. The surface of grain adjacent to the intergranular phase (surface No. 1) and the surface of intergranular phase adjacent to the grain (surface No. 2) create the first interface. The second interface is formed by the surface of intergranular phase adjacent to the matrix (surface No. 3) and the surface of matrix adjacent to intergranular phase (surface No. 4). Stresses calculations and analysis of their heterogeneity were performed for these surfaces. Ceramic system $Al_2O_3$-MgO-$Al_2O_3$ was researched. In this system the grain and the matrix were made of $Al_2O_3$ (density $\rho$ = 4.0 g/cm$^3$, the modulus of elasticity $E$ = 380 GPa, Poisson's ratio $\mu$ = 0.24 and temperature coefficient of thermal expansion $\alpha$ = 8.5 × 10$^{-6}$ K$^{-1}$, $\lambda$ = 2100 T - 0.78 W/(m × K) and intergranular phase was made of MgO ($\rho$ = 3.4 g/cm$^3$; $E$ = 315 GPa; $\mu$ = 0.18; $\alpha$ = 13.4 × 10$^{-6}$ K$^{-1}$, $\lambda$ = 7871.2 / (T - 125) + 3.6 × 10$^{-33}$ T$^{10}$ W/(m × K).

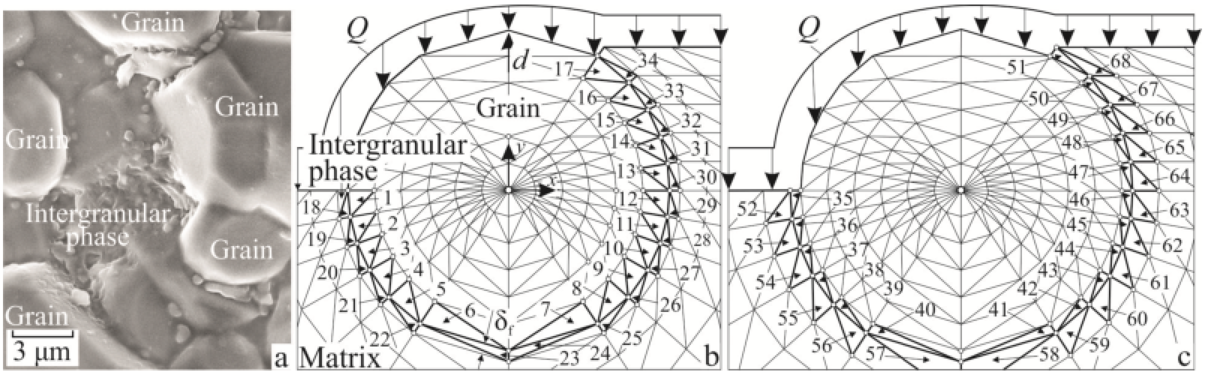


Fig. 1: Surface structure of oxide ceramics, calculation scheme and location of control points.

Numerical experiments were performed in automated system RKS-ST v.1.0 [4]. The heat flow $Q$ = 1.2, 1.5 and 1.6 $\times$ $10^9$ W/m$^2$ was applied to the free surface of all ceramic structural elements. The heat removal was carried out in the internal volumes of ceramics, convective heat transfer was not used. The method of control points (CP) was used to analyse the results of numerical experiments [5]. Selected CP 1 - 17, CP 18 - 34 (Fig. 1, b), CP 35 - 51 and CP 52 -68 (Fig. 1, c) were located in the surfaces No. 1, No. 2, No. 3 and No. 4 accordingly. The stress heterogeneity was characterized by maximum, minimum and average stresses as well as the range of their variation.

## 3 Results and Discussion

The ceramic surface layer is heated and a temperature field is formed under the influence of heat flow. The highest temperatures $T$ = 790, 1143 and 1279 °C in the considered structures are formed in the CP of surface 1 and the lowest temperatures $T$ = 346, 472 518 °C are formed in the CP of surface 4 under the action of heat flows $Q$ = 1.2, 1.5 and 1.6 $\times$ $10^9$ W/m$^2$ respectively. The ceramic surface layer is deformed under the scheme of squeezing the grain from the matrix.

The character of changes of stresses $\sigma_{11}$, $\sigma_{12}$ and $\sigma_{22}$ in the surfaces of the structural elements of ceramic system $Al_2O_3$-MgO-$Al_2O_3$ under the action of heat flow $Q$ = 1.5 $\times$ $10^9$ W/m$^2$ is shown in Fig. 2. The stress heterogeneity in each selected surface is analyzed consistently. Surface No. 1 (Fig. 2, a). The stresses $\sigma_{11}$ are changed in the range $\Sigma$ = 817.9 MPa from - 1208 MPa (CP2) to - 390.1 MPa (CP17) when their average value $\sigma_a$ = - 852 MPa. The stresses $\sigma_{22}$ are changed in the range $\Sigma$ = 479.9 MPa from - 390 (CP1) to 89.9 MPa (CP17) when $\sigma_a$ = - 88 MPa. The stresses $\sigma_{12}$ are changed in the range $\Sigma$ = 222 MPa from - 266.5 (CP10) to - 44,41 MPa (CP4) when $\sigma_a$ = - 160 MPa. Surface No. 2 (Fig. 2, b). The stresses $\sigma_{11}$ are changed in the range $\Sigma$ = 638.1 MPa from - 1253 MPa (CP22) to - 614.9 MPa (CP34) when $\sigma_a$ = - 1007 MPa. The stresses $\sigma_{22}$ are changed in the range $\Sigma$ = 692.8 MPa from - 832,9 MPa (CP18) to - 140,1 (CP24) when $\sigma_a$ = - 439 MPa. The stresses $\sigma_{12}$ are changed in the range $\Sigma$ = 513 MPa from - 389 (CP26) to 124 MPa (CP21) when $\sigma_a$ = - 134 MPa. Surface No. 3 (Fig. 2, c). The stresses $\sigma_{11}$ are changed in the range $\Sigma$ = 1570.7 MPa from - 2060 MPa (CP35) to - 489.3 MPa (CP51) when $\sigma_a$ = - 1000 MPa. The stresses $\sigma_{22}$ are changed in the range $\Sigma$ = 749 MPa from - 809.2 MPa (CP35) to - 60.1 MPa (CP41) when $\sigma_a$ = - 408 MPa. The stresses $\sigma_{12}$ are changed in the range $\Sigma$ = 572.3 MPa from - 422,4 MPa (CP43) to 149,9 MPa (CP39) when $\sigma_a$ = - 129,5 MPa. Surface No. 4 (Fig. 2, d). The stresses $\sigma_{11}$ are changed in the range $\Sigma$ = 795.9 MPa from - 1233 MPa (CP52) to - 437.1 MPa (CT68) when $\sigma_a$ = - 846 MPa. The stresses $\sigma_{22}$ are changed in the range $\Sigma$ = 243.4 MPa from - 201.6 MPa (CP57) to 41.88 MPa (CP65) when $\sigma_a$ = - 66,7 MPa. The stresses $\sigma_{12}$ are changed in the range $\Sigma$ = 210.3 MPa from 254.7 MPa (CP52) to - 44.35 MPa (CP57) when $\sigma_a$ = - 172 MPa.

Fig. 3 shows the variation of the stresses intensity $\sigma$i in surfaces of the structural elements of ceramic system $Al_2O_3$-MgO-$Al_2O_3$ under the influence of different heat flows. It is seen that the increase of heat flow leads to the increase $\sigma$i in all surfaces of structural elements without changing the shape of the curves. The stress heterogeneity in each selected surface is analyzed consistently.

Surface No. 1 (Fig. 3, a). The stress intensity $\sigma_i$ varies in the range $\Sigma$ = 385.3 MPa from 610.7 MPa (CP17) to 996 MPa (CP2) when $\sigma_a$ = 762 MPa under the action of a heat flow $Q$ = 1,2 $\times$ $10^9$ W/m$^2$. The stress intensity $\sigma_i$ varies in the range $\Sigma$ = 653.5 MPa from 453.5 MPa (CP17) to 1107 MPa (CP2) when $\sigma_a$ = 875 MPa

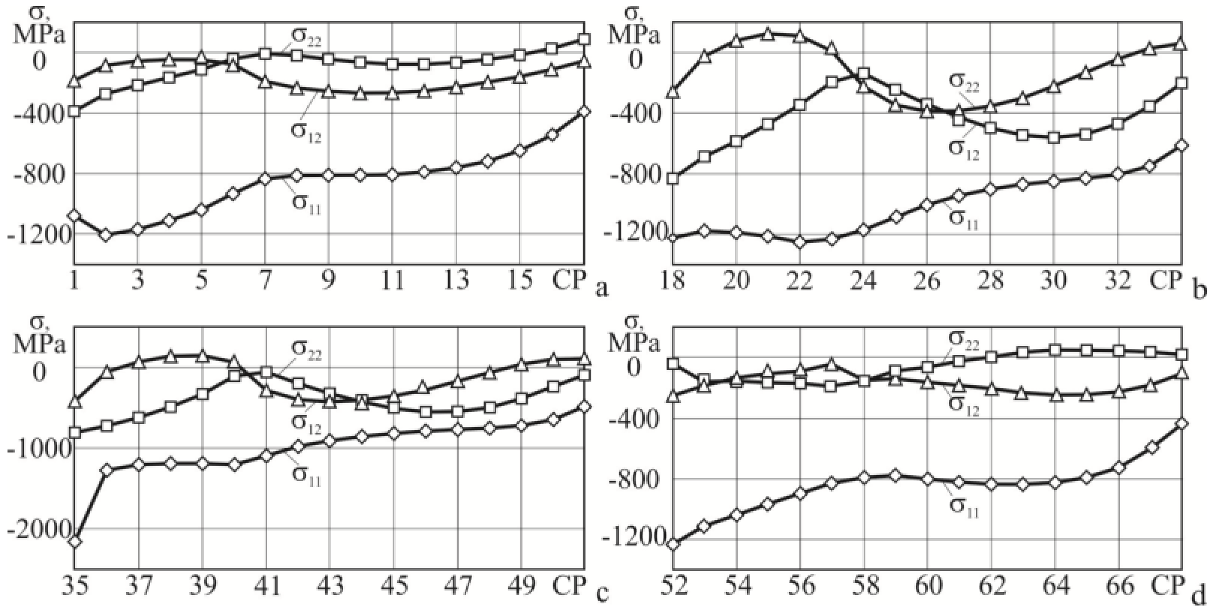


Fig. 2: Character of changes of stresses $\sigma_{11}$, $\sigma_{12}$ and $\sigma_{22}$ in the surfaces No. 1 (a), 2 (b), 3 (c) and 4 (d) ceramic system $Al_2O_3$-MgO-$Al_2O_3$ under the action of heat flow $Q$ = 1.5 × $10^9$ W/m$^2$.

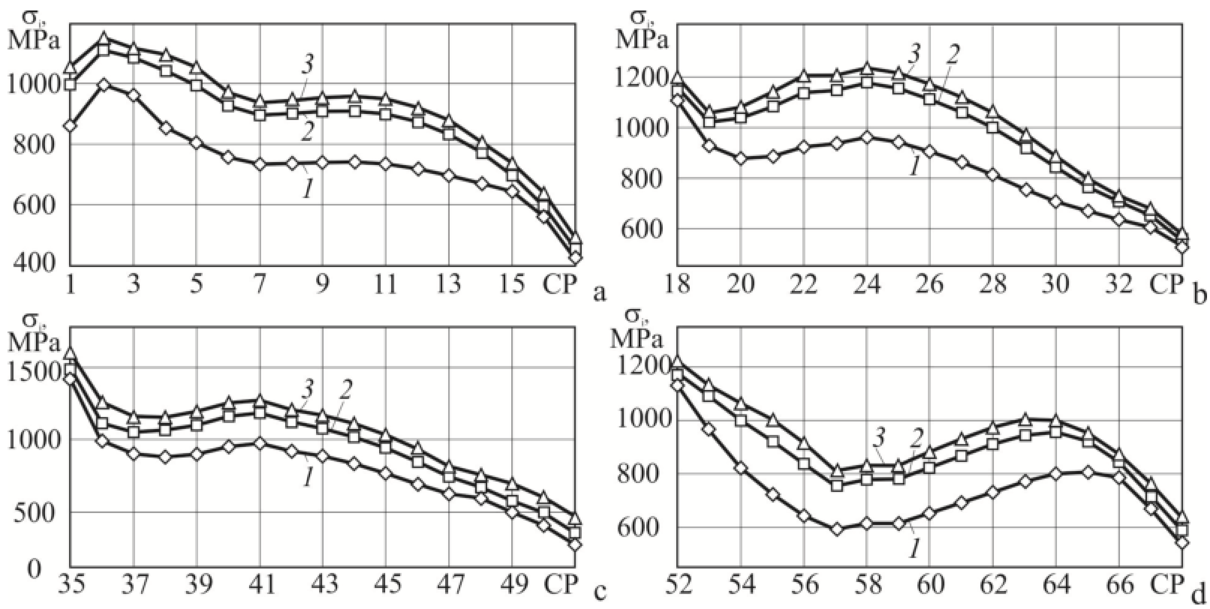


Fig. 3: Character of changes of stress intensity $\sigma_i$ in the surfaces No. 1 (a), 2 (b), 3 (b) and 4 (d) ceramic system $Al_2O_3$-MgO-$Al_2O_3$ under the influence heat flows: 1 - $Q$ = 1.2 × $10^9$ W/m$^2$; 2 - $Q$ = 1.5 × $10^9$ W/m$^2$; 3 - $Q$ = 1.6 × $10^9$ W/m$^2$.

under the action of flow $Q$ = 1,5 × $10^9$ W/m$^2$. The stress intensity $\sigma_i$ varies in the range Σ = 764.5 MPa from 348.5 MPa (CP17) to 1113 MPa (CP2) when $\sigma_a$ = 891 MPa under the action of flow $Q$ = 1.6 × $10^9$ W/m$^2$. Surface No. 2 (Fig. 3, b). Stress intensity $\sigma_i$ varies in the range Σ = 521 MPa 670 MPa (CP31) to 1191 MPa (CP18) when $\sigma_a$ = 853 MPa under the action of flow $Q$ = 1,2 × $10^9$ W/m$^2$. Stress intensity $\sigma_i$ varies in the range Σ = 624.9 MPa from 551.1 MPa (CP34) to 1176 MPa (CP24) when $\sigma_a$ = 972.4 MPa under the action of flow $Q$ = 1.5 × $10^9$ W/m$^2$. Stress intensity $\sigma_i$ varies in the range Σ = 941,2 MPa from 292.8 MPa (CP34) to 1234 MPa (CP24) when $\sigma_a$ = 978 MPa under the action of a heat flux $Q$ = 1.6 × $10^9$ W/m$^2$. Surface No. 3 (Fig. 3). Stress intensity $\sigma_i$ varies in the range Σ = 1534 from 598 MPa MPa (CP48) to 2132 MPa (CP35) when $\sigma_a$ = 897 MPa under the action of flow $Q$ = 1.2 × $10^9$ W/m$^2$. Stress intensity $\sigma_i$ varies in the range Σ = 1453,3 MPa from 484,7 MPa (CP51) until 1938 MPa (CP35) when $\sigma_a$ = 987 MPa under the action of flow $Q$ = 1,5 × $10^9$ W/m$^2$. Stress intensity $\sigma_i$ varies in the range Σ = 1391,6 MPa from 177,4 MPa (CP51) until 1569 MPa (CP35) when $\sigma_a$ = 966 MPa under the action of flow $Q$ = 1.6 × $10^9$ W/m$^2$. Surface No. 4 (Fig. 3, g). Stress intensity $\sigma_i$ varies in the range Σ = 681,2 MPa from 591,8 MPa (CP57) to 1273 MPa (CP52) when $\sigma_a$ = 756 MPa under the action of flow $Q$ = 1.2 × $10^9$ W/m$^2$. Stress intensity $\sigma_i$ varies in the range Σ = 806,3 MPa from 478,7 MPa (CP68) to 1285 MPa (CP52) when $\sigma_a$ = 875 MPa under the action of flow $Q$ = 1.5 × $10^9$ W/m$^2$. Stress intensity $\sigma_i$ varies in the range Σ = 861.8 MPa from over 322.2 MPa (CP68) to 1184 MPa (CP52) when $\sigma_a$ = 897 MPa under the action of flow $Q$ = 1.6 × $10^9$ W/m$^2$.

## 4 Conclusion

Based on the analysis of the results of numerical experiments the conclusion about the significant influence of a single defect on the stress state of the surface layer of oxide ceramics is made. It is characterized by high stress heterogeneity of $\sigma_{11}$, $\sigma_{22}$, $\sigma_{12}$ and $\sigma_i$. For example, under the action of heat flow $Q$ = 1.5 × $10^9$ W/m$^2$ the highest value of stress intensity $\sigma_i$ = 1938 MPa is fixed in surface No. 3 that is 43, 40 and 34 % higher than the similar indicator for surfaces No. 1 and No. 2 and No. 4 respectively. The greatest range of variation of stress intensity Σ = 1453.3 MPa is fixed in surface No. 3 that on 55, 57 and 45 % higher than the similar indicator for surfaces No. 1, No. 2 and No. 4 respectively.

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