EFFECT OF TITANIUM NITRIDE COATING ON STRESS STRUCTURAL INHOMOGENEITY IN OXIDE-CARBIDE CERAMIC. PART 3. ACTION OF DISTRIBUTED FORCE LOAD[1]

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The effect of a titanium nitride coating on stress structural inhomogeneity in oxide-carbide ceramic under action of a distributed force load is studied. The effect of a coating on properties determining stress structural inhomogeneity within ceramic is established. A requirement is noted for considering stress structural inhomogeneity in designing objects from oxide-carbide ceramic with a coating.

Keywords: ceramic, coating, stress structural inhomogeneity, distributed force load, structural element.

INTRODUCTION

The aim of research is analysis of the effect of a titanium nitride coating on the stress-strained state of structural elements of oxide-carbide ceramic under action of a concentrated force. Solution of this scientific problem will supplement features of the effect of force loads on stress-strained state of ceramic materials provided in [1 – 4].

The procedure for revelation and analysis of structural inhomogeneity of stresses σ_{11}, σ_{22}, σ_{12} and stress intensity σ_i in a surface (surface layer) of ceramic structural elements under action of an external load has been provided in [5]. More detailed aspects of this procedure are given in [6 – 9].

RESULTS AND DICUSSION

A plate of oxide-carbide ceramic without a coating (system TiC–MgO–Al$_2$O$_3$)–SCh32) and with a titanium nitride coating 5 μm thick (system TiC–MgO–Al$_2$O$_3$)–TiN–SCh32) under action of a distributed load P deforms by the scheme presented in Fig. 1. Grains in ceramic of the system (TiC–MgO–Al$_2$O$_3$)–SCh32 (Fig. 1*a*) and (TiC–MgO–Al$_2$O$_3$)– TiN–SCh32 (Fig. 1*b*) from starting position 3 move
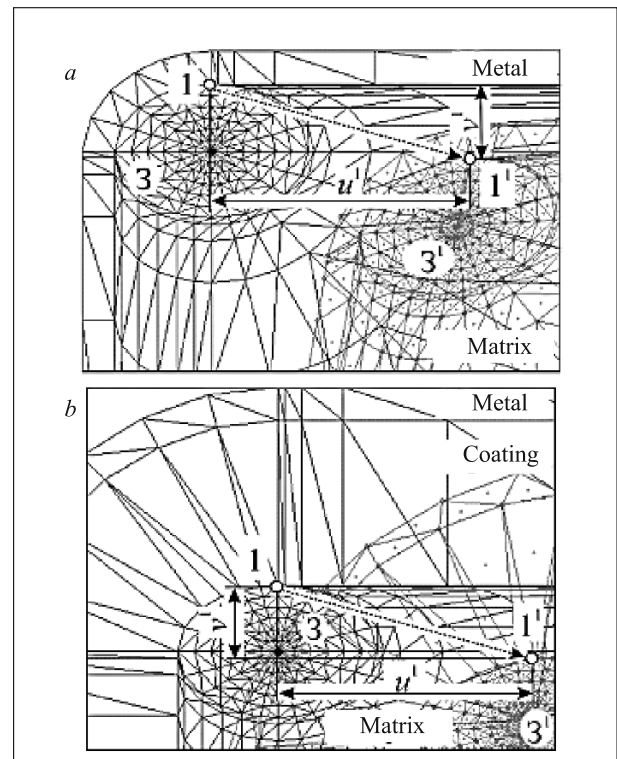

Fig. 1. Diagrams of ceramic of the systems (TiC–MgO–Al$_2$O$_3$)–SCh32 (*a*) and (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 (*b*) under action of distributed force $P = 4.0 \times 10^8$ Pa.
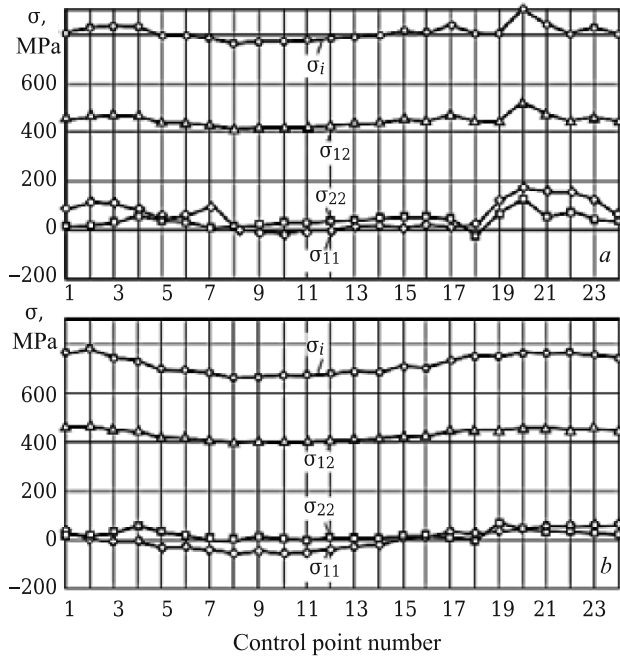
Fig. 2. Stresses at CP of a grain surface of ceramic of the systems $(TiC–MgO–Al_2O_3)$–SCh32 (*a*) and $(TiC–MgO–Al_2O_3)$–TiN–SCh32 (*b*) under action of distributed force $P = 4.0 \times 10^8$ Pa.

Fig. 3. Stresses at CP of intergranular phase surface adjacent to a grain of ceramic of the systems $(TiC–MgO–Al_2O_3)$–SCh32 (*a*) and $(TiC–MgO–Al_2O_3)$–TiN–SCh32 (*b*) under action of distributed force $P = 4.0 \times 10^8$ Pa.

within the internal volume of ceramic occupying position 3^1. As an example in diagrams the trajectory of CP movement from an original position 1 into deformed position 1^1, and values of its horizontal u^1 and vertical v^1 displacements are shown. It is seen that the greatest movement of CP1 occurs in a horizontal direction.

The nature of change of stresses σ_{11}, σ_{22}, σ_{12} and σ_i at CP of surfaces of different structural elements of ceramic of the systems $(TiC–MgO–Al_2O_3)$–SCh32 and $(TiC–MgO–Al_2O_3)$–TiN–SCh32 under action of distributed force $P = 4.0 \times 10^8$ Pa is shown in Figs. 2 – 5. Successively we consider the results obtained as applied to each surface and system.

In a surface layer of a grain of the system $(TiC–MgO–Al_2O_3)$–SCh32 (see Fig. 2*a*) stresses σ_{11} form, which vary in the range 140.24 MPa, i.e., from –11.94 at CP10 to 128.3 MPa at CP20 with an average value (taking account of sign) $\sigma_{av} = 41.98$ MPa and standard deviation $s = 45.8$ MPa. These stresses change sign twice: between CP8 and CP9 and between CP12 and CP13. Stress σ_{22} varies in the range 142.35 MPa, i.e., from –14.65 at CP2 to 127.7 MPa at CP20 with $\sigma_{av} = 42.38$ MPa and $s = 27$ MPa. The curve for each intersects the zero line at section CP17 – CP18. Stress σ_{12} varies in the range 73.3 MPa, i.e., from 436.3 at CP8 to 509.6 MPa at CP20 with $\sigma_{av} = 460.95$ MPa and $s = 16.55$ MPa, and stress does not change sign over the whole surface layer. Stress intensity σ_i varies in the range of 136 MPa, i.e., from 756 at CP8 to 892 MPa at CP20 with $\sigma_{av} = 798.6$ MPa and
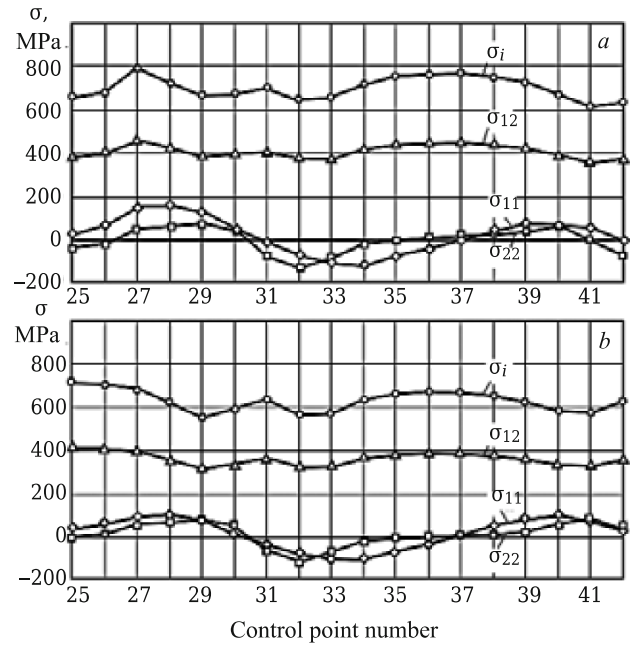
$s = 29.28$ MPa. The change in value of stress intensity σ_i in the surface of a grain is stable in nature.

In the surface layer of a grain of the system $(TiC–MgO–Al_2O_3)$–TiN–SCh32 (see Fig. 2*b*) stresses σ_{11} form, which vary in the range 83.7 MPa i.e., from –48.4 at CP10 to 35.3 MPa at CP24 with $\sigma_{av} = -5.82$ MPa and $s = 28.59$ MPa. These stresses change sign twice: between CP1 and CP2 and between CP15 and CP16. Stresses σ_{22} vary in the range 53.7 MPa, i.e., from –5.6 at CP7 to 48.1 MPa at CP19 with $\sigma_{av} = 12.14$ MPa and $s = 14.23$ MPa. The curve crosses the zero line five times: first time between CP6 and CP7 and four times in section CP7 – CP18. Stresses σ_{12} vary in the range of 59 MPa, i.e., from 389 at CP8 to 448 MPa at CP2 with $\sigma_{av} = 419.54$ MPa and $s = 20.92$ MPa, and stress does not change sign over the whole surface layer. Stress intensity σ_i varies in the range 100 MPa. i.e., from 676 at CP8 to 776 MPa at CP2 with $\sigma_{av} = 727.29$ MPa and $s = 35.74$ MPa. The change in value of stress intensity σ_i in the surface layer of a grain of the system $(TiC–MgO–Al_2O_3)$–TiN–SCh32 is also stable in nature.

In the surface layer of intergranular phase, adjacent to a grain of the system $(TiC–MgO–Al_2O_3)$–SCh32 (see Fig. 3*a*), stresses σ_{11} form, which vary in the range 264.8 MPa, i.e., from –99 at CP34 to 165.8 MPa at CP28 with $\sigma_{av} = 30.52$ MPa and $s = 83.2$ MPa. Stresses change sign three times: first time between CP31 and CP32, second time between CP36 and CP37, third time between CP41 and CP42. Stresses σ_{22} vary in the range 231.6 MPa, i.e., from –118.5 at CP32 to
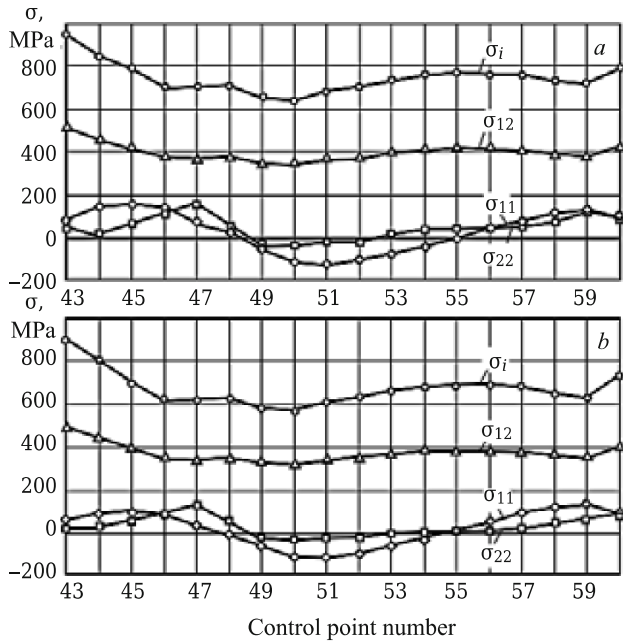
Fig. 4. Stresses at CP of intergranular phase surface adjacent to matrix of ceramic of the systems (TiC–MgO–Al$_2$O$_3$)–SCh32 (*a*) and (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 (*b*) under action of distributed force $P = 4.0 \times 10^8$ Pa.

Fig. 5. Stresses at CP of intergranular phase surface adjacent to intergranular of ceramic of the systems (TiC–MgO–Al$_2$O$_3$)–SCh32 (*a*) and (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 (*b*) under action of distributed force $P = 4.0 \times 10^8$ Pa.

113.1 MPa at CP29 with $\sigma_{av} = 35.03$ MPa and $s = 64.33$ MPa. The curve crosses the zero line three times: first time between CP26 and CP27 and twice more in section CP30 – CP34. The nature of the curve is almost the same as the dependence of σ_{11}. Stresses σ_{12} vary in the range 97.8 MPa, i.e., from 347.6 at CP41 to 445.4 MPa at CP27 with $\sigma_{av} = 396.18$ MPa and $s = 29.57$ MPa. These stresses do not change sign over the whole surface. The intensity of stresses σ_i varies in the range 175.3 MPa, i.e., from 608.7 at CP41 to 784 MPa at CP27 with $\sigma_{av} = 691.96$ MPa and $s = 51.02$ MPa. The change in stress intensity σ_i within a surface layer of intergranular phase, adjacent to a grain, is quite stable in nature, and there is an insignificant increase in stress in two sections: CP25 – CP27 (from 651 to 784 MPa) and CP29 – CP36 (from 657 to 757 MPa).

Within the surface layer of intergranular phase, adjacent to a grain of the system (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 (see Fig. 3*b*), stresses σ_{11} form, which vary in the range 204.9 MPa, i.e., from –115.6 at CP33 to 89.3 MPa at CP28 with $\sigma_{av} = 4.84$ MPa and $s = 69.47$ MPa. Stresses σ_{11} change sign twice: first time between CP30 and CP31, second time between CP37 and CP38. Stresses σ_{22} vary in the range 213.6 MPa, i.e., from 122.5 at CP32 to 91.11 MPa at CP41 with $\sigma_{av} = 12.69$ MPa and $s = 58.38$ MPa. The curve crosses the zero line three times: first time between CP25 and CP26 and twice more in section CP30 – CP37. Stresses σ_{12} vary in the range 83.4 MPa, i.e., from 327 at CP29 to 410.4 MPa at CP25 with $\sigma_{av} = 363.05$ MPa and $s = 26.19$ MPa. Stresses

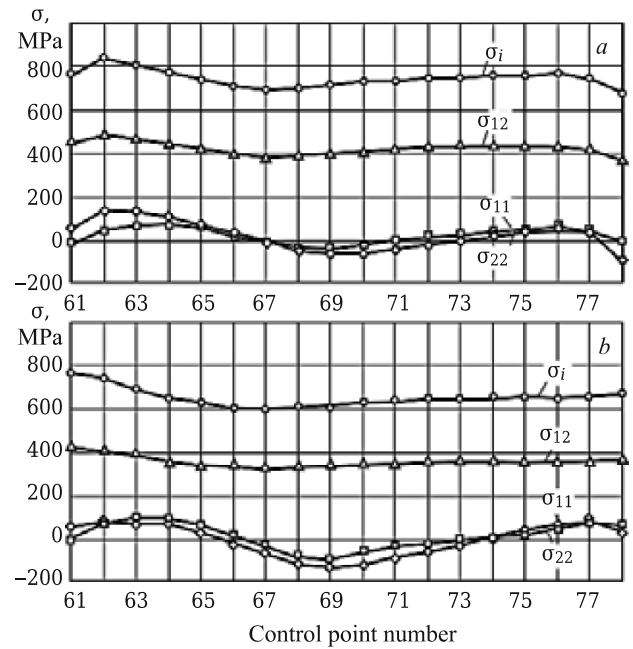σ_{12} do not change sign over the whole surface layer. The intensity of stresses σ_i varies in the range 134 MPa, i.e., from 572 at CP29 to 711 MPa at CP25 with $\sigma_{av} = 632.83$ MPa and $s = 43.35$ MPa.

In the surface layer of intergranular phase, adjacent to matrix of the system (TiC–MgO–Al$_2$O$_3$)–SCh32 (see Fig. 4*a*), stresses σ_{11} form, which vary in the range 267.5 MPa, i.e., from 108.1 at CP51 to 159.4 MPa at CP45 with $\sigma_{av} = 40.75$ MPa and $s = 87.87$ MPa. Stresses change sign twice: first between CP48 and CP49, and second between CP54 and CP55. Stresses σ_{22} change in the range 197.6 MPa, i.e., from –36.6 at CP50 to 161 MPa at CP47 with $\sigma_{av} = 50.73$ MPa and $s = 52,93$ MPa. The curve crosses the zero line twice, i.e., between CP48 and CP49, second time between CP52 and CP53. Stresses σ_{12} vary in the range 174.6 MPa, i.e., from 367 at CP50 to 541,6 MPa at CP43 with $\sigma_{av} = 425,49$ MPa and $s = 39.99$ MPa. These stresses do not change sign over the whole surface. The intensity of stresses σ_i varies in the range 300.4 MPa, i.e., from 641 at CP50 to 941.4 MPa at CP43 with $\sigma_{av} = 743.35$ MPa and $s = 69.44$ MPa.

In the surface layer of intergranular phase, adjacent to matrix of the system (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 (see Fig. 4*b*), stresses σ_{11} form, which vary in the range 237.3 MPa, i.e., from –127 at CP51 to 110.3 MPa at CP59 with $\sigma_{av} = 5$ MPa and $s = 78.86$ MPa. Stresses σ_{11} change sign twice: first time between CP47 and CP48, second time between CP55 and CP56. Stresses σ_{22} vary in the range
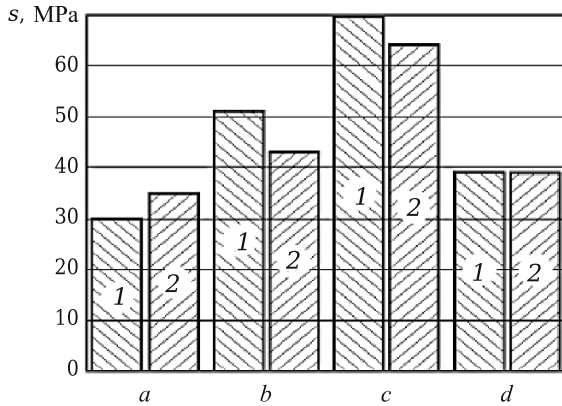
Fig. 6. Standard deviation s of stress intensity in a grain surface layer (a), intergranular phase adjacent to a grain (b) and matrix (c), matrix adjacent to intergranular phase (d) for systems (TiC–MgO–Al$_2$O$_3$)–SCh32 (a) and (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 (b) under action of distributed force $P = 4.0 \times 10^8$ Pa.

Fig. 7. Effect of distributed for P on stress intensity σ_i in surface of a grain (1, 4), intergranular phase, adjacent to a grain (2, 5) and matrix (3, 6), matrix, adjacent to intergranular phase (4, 8) of different systems: $1 – 4$) system (TiC–MgO–Al$_2$O$_3$)–SCh32; $5 – 8$) system (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32.

182.7 MPa, i.e., from –50.7 at CP50 to 132 MPa at CP47 with $\sigma_{av} = 22.71$ MPa and $s = 50.65$ MPa. The curve crosses the zero line twice: first between CP48 and CP49, second between CP54 and CP55. Stresses σ_{12} vary in the range 161 MPa. i.e., from 330 at CP50 to 491 MPa at CP43 with $\sigma_{av} = 380.11$ MPa and $s = 38.55$ MPa. Over the whole surface layer these stresses do not change sign. Stress intensity σ_i varies in the range 270 MPa, i.e., from 581 at CP50 to 851 MPa at CP43 with $\sigma_{av} = 663.1$ MPa and $s = 64,74$ MPa.

In a surface layer of matrix, adjacent to intergranular phase of the system (TiC–MgO–Al$_2$O$_3$)–SCh32 (see Fig. 5a), stresses σ_{11} form, which vary in the range 241.3 MPa, i.e., from –88.7 at CP78 to 152.6 MPa at CP62 with $\sigma_{av} = 31.87$ MPa and $s = 69.56$ MPa. These stresses change sign three times: first time between CP67 and CP68, second time between CP72 and CP73, and third time between CP77 and CP78. Stresses σ_{22} vary in the range 125.1 MPa, i.e., from –30.05 at CP69 to 95.05 MPa at CP47 with $\sigma_{av} = 38.94$ MPa and $s = 39.49$ MPa. The curve crosses the zero line three times: first time between CP61 and CP62 and twice in section CP67 – CP70. Stresses σ_{12} vary in the range 89.7 MPa, i.e., from 376.3 at CP78 to 466 MPa at CP62 with $\sigma_{av} = 415.28$ MPa and $s = 21.2$ MPa. These stresses do not change sign over the whole extent of the curve. Stress intensity σ_i varies in the range 160 MPa, i.e., from 658 at CP78 to 818 MPa at CP62 with $\sigma_{av} = 722.84$ MPa and $s = 38.77$ MPa.

In a surface layer of matrix, adjacent to intergranular phase of the system (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 (see Fig. 5b), stresses σ_{11} form, which vary in the range 139 MPa, i.e., from –84 at CP69 to 55 MPa at CP63 with $\sigma_{av} = –2.17$ MPa and $s = 49.29$ MPa. Stresses change sign twice: first time between CP65 and CP66, second time between CP73 and CP74. Stresses σ_{22} vary in the range 121 MPa, i.e., from –50 at CP69 to 71 MPa at CP64 with
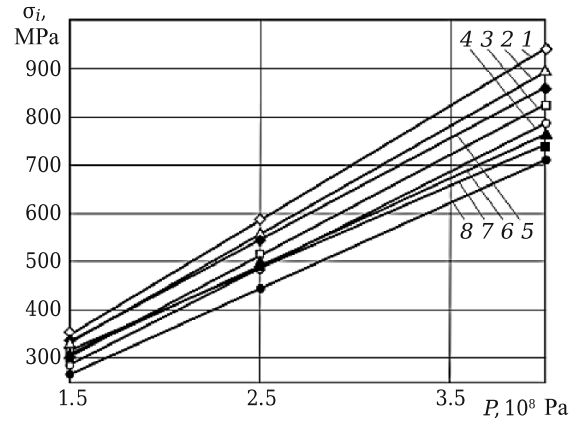
$\sigma_{av} = 16.19$ MPa and $s = 36.8$ MPa. The curve crosses the zero line twice in a short section: first time between CP66 and CP67, second time between CP72 and CP73. Stresses σ_{12} vary in the range 88 MPa, i.e., from 345 at CP67 to 433 MPa at CP61 with $\sigma_{av} = 374.83$ MPa and $s = 22.36$ MPa, and stress does not change sign over the whole extent of the curve. Stress intensity σ_i varies in the range 153 MPa, i.e., from 599 at CP67 to 752 MPa at CP61 with $\sigma_{av} = 650.78$ MPa and $s = 38.84$ MPa.

The effect of TiN containing on standard deviation of stress intensity values at CP in a surface layer of structural elements of the two systems is shown in Fig. 6.

The greatest value of standard deviation ($s = 69.43$ MPa) is recorded in a surface layer of intergranular phase adjacent to matrix in the system (TiC–MgO–Al$_2$O$_3$)–SCh32, and the least ($s = 29.3$ MPa) is recorded in a surface layer of a grain of this system.

The greatest value of standard deviation ($s = 69.43$ MPa) was recorded in a surface layer of intergranular phase adjacent to matrix in the system (TiC–MgO–Al$_2$O$_3$)–SCh32, and the least ($s = 29.3$ MPa) in the surface layer of a grain of this system. In the surface layer of ceramic grain with a coating an increase is noted in standard deviation for stress intensity

TABLE 1

CP position at surface	(TiC–MgO–Al$_2$O$_3$)–SCh32	(TiC–MgO–Al$_2$O$_3$)–TiN–SCh32
Grain	CP20	CP2
Intergranular phase, adjacent to grain	CP27	CP25
Intergranular phase, adjacent to matrix	CP43	CP43
Matrix	CP62	CP61

σ_i by a factor of 1.2 compared with uncoated ceramic. The coating reduces the value of standard deviation of σ_i by factor of 1.2 and 1.1 in surface layers of intergranular phase adjacent to a grain and matrix. A coating does not change the value of standard deviation of σ_i in a matrix surface layer.

The effect of distributed load on stresses σ_{11}, σ_{22}, σ_{12} and σ_i in different surface elements of the structure of the systems (TiC–MgO–Al$_2$O$_3$)–SCh32 and (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 was studied. For this purpose a structure was successively loaded with distributed load P, equal to 1.5×10^8, 2.5×10^8 and 4.0×10^8 Pa. For analysis in each system CP were used in which the greatest stress values were recorded. A list of these CP is provided in Table 1. As an example results are shown in Fig. 7 for these numerical experiments with respect to stress intensity σ_i.

It has been established that an increase in concentrated force increases the value of σ_i linearly in surface layers of all ceramic structural elements. The most marked increase is recorded within surface layers of structural elements of the system (TiC–MgO–Al$_2$O$_3$)–SCh32, and the least for the system (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32.

CONCLUSION

It has been established that a TiN coating 5 μm thick does not fundamentally change the deformation scheme for structural elements of oxide-carbide ceramic under action of a distributed force load. A favorable effect of this coating on stress-strained state of surface structural elements of oxide-carbide ceramic develops mainly as a reduction in the range of variation of stresses σ_{11}, σ_{22}, σ_{12}, and stress intensity σ_i. An ambiguous effect of a coating has been revealed on the stress-strained state of the surface of structural elements of oxide-carbide ceramic.

The surface layer of a grain is most sensitive to a coating within which the range of change in σ_{11}, σ_{22}, σ_{12} and σ_i decreased by a factor of 1.2 to 2.65, and the range of change in σ_i in this layer decreased by a factor of 1.36. In surface layers of intergranular phase adjacent to a grain and to matrix, and also within a surface layer of matrix a reduction was recorded in the range of change of σ_{11}, σ_{22}, σ_{12} and σ_i by factors of 1.1 – 1.29, 1.09 – 1.12, and 1.02 – 1.73 respectively. The range of change in σ_i in these surface layers decreased by factors of 1.26, 1.11, and 1.05 respectively, which points to marked significance of the scale factor on the effect of TiN coating on surface structural element stress-strained state of oxide-carbide ceramic under action of a distributed force load.

A positive change also concerns the reduction in maximum and average stresses at CP of the surface of all structural elements of ceramic of the system (TiC–MgO–Al$_2$O$_3$)–

TiN–SCh32 compared with indices for ceramic of the system (TiC–MgO–Al$_2$O$_3$)–SCh32.

A coating ambiguously affects stress inhomogeneity within the surface layer of ceramic structural elements. A reduction was recorded in standard deviation of σ_{11}, σ_{22}, σ_{12}, and σ_i at CP the surface of intergranular phase adjacent to a grain and matrix. At CP of a grain surface and matrix for ceramic of the system (TiC–MgO–Al$_2$O$_3$)–TiN–SCh32 the standard deviation of σ_{11} and σ_{22} decreases, but σ_{12} and σ_i increase compared with indices for ceramic of the system (TiC–MgO–Al$_2$O$_3$)–SCh32.

A coating hardly alters the number of changes in sign of stresses at CP of the surface of structural elements of oxide-carbide ceramic under action of a distributed load, but increases this index by factors from 2 to 5 with respect to stress σ_{22} within a grain surface layer.

A change in stress-strained state of the main structural elements should be considered in designing oxide-carbide ceramic objects for prescribed operating conditions.

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