ACTION OF EXPLOSIVE LOADS ON A METASTABLE ZIRCONIUM-DIOXIDE STRUCTURE

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The influence of nonuniformity of the initial zirconium dioxide on the polymorphic and structural transformations in explosive loading is investigated. In the highly disperse quenched structure t'-ZrO₂, there is further reduction in domain size if their boundaries are not stabilized by an Al₂O₃ glass phase. In preliminarily annealed equilibrium t-ZrO₂, as a result of loading, the structure becomes increasingly fragmentary and prone to t → m transformation. In repeated explosive loading, the structural changes in quenched t'-ZrO₂ and annealed t-ZrO₂ are similar.

The action of explosive loading on tetragonal zirconium dioxide with a t'-structure stabilized in various ways is investigated. As in [1], we study the transformation of nonequilibrium ZrO₂ with a complex initial structure as a result of plasmochemical synthesis, including heating above 2000°C and sharp quenching, which leads to the formation of highly disperse powder; the powder particles are hollow spheres with a mean diameter of 0.4 μm.

The glass material of such spheres has a domain structure with a characteristic dimension of ~ 200 Å; this is usually called the t' phase [1]. It is nonequilibrium in two respects: first, it is characterized by phase metastability, since the monoclinic phase is stable at room temperature according to the equilibrium state diagram. Second, the material has a highly disperse quenched structure with a large quantity of subboundaries, which indicates structural instability.

In [2], the effect of explosion on metastable martensitic alloys and other defect-saturated structures was investigated, and it was concluded that the presence of disoriented subboundaries and their stability in pulsed-loading conditions are decisive. Quenched t'-ZrO₂ has a highly disperse inlaid structure with mutually perpendicular ferroelastic domains and with a developed subboundary system [3]. The stability of these boundaries in various conditions determines the useful properties of tetragonal ZrO₂ and their tendency to undergo transition to monoclinic phase.

The stability with respect to t' → m phase transition is increased on introducing Y³⁺ cations, for example, in the ZrO₂ lattice; this leads to the formation of oxygen vacancies, reducing the mobility of the atoms and boundaries. In turn, the boundaries of the ferroelastic domains constituting the t' phase themselves act as a stabilizing factor hindering the martensitic transition t' → m. Adding Al₂O₃ has a greater stabilizing effect on the t'-phase [1]; partial segregation of Al₂O₃ at the boundaries facilitates the locking of glass-phase domain boundaries [4, 5]. Indirect confirmation that Al₂O₃ is in the amorphous state may be seen in that the X-ray diffraction pattern does not include lines corresponding to Al₂O₃ as an independent phase, despite its high content in the material (~ 20%); usually, 3-5% crystalline Al₂O₃ is seen. According to the ZrO₂—Al₂O₃ state diagram, no more than 5% Al₂O₃ may be in solution. The remaining ~15% of the Al₂O₃ is most likely distributed in thin amorphous layers along the numerous boundaries. The influence of added Al₂O₃ on the position and shape of the ZrO₂ X-ray lines was described in [1].

In the experiments, the following materials were subjected to the same explosive load: 1) quenched t'-ZrO₂ powder stabilized by 3% Y₂O₃; 2) the same powder after preliminary annealing at 1200°C for 1 h to obtain the recrystallized equilibrium t-structure; 3) quenched t'-ZrO₂ stabilized by adding 20% Al₂O₃.

The powder is tested in steel cylindrical ampules (length 150 mm, internal diameter 28 mm) using an ammonite charge of thickness 7 mm with a detonation rate of 3.5 km/sec; the packing density of the powder is 1.1 g/cm³. Note that the structural

change is largely independent of the loading pressure (replacement of ammonite with hexogen) and of the ampule and charge dimensions. The deformation at the stage of powder compression is evidently studied here. In addition, experiments are conducted with repeated loading of the ampule by an analogous charge without intermediate extraction of the powder.

After explosive loading, the material is investigated by X-ray structural analysis on a DRON-3 diffractometer in Cu Kα radiation with a graphite monochromator; this ensures practical elimination of the background on the diffraction pattern and allows the shoulders of the diffraction lines to be taken into account; it also lowers the threshold of observation for the ZrO2 m-phase to 1.5-2%. The content of monoclinic phase is determined from the integral-intensity ratio of the lines (111)m, (111)t, and (111)m with the introduction of additives according to [6]. The width and shape of the tetragonal-phase diffraction lines are also analyzed; this characterizes the dispersity and defect content of the crystalline structure.

The initial quenched ZrO2 contains ~2% monoclinic phase. Recrystallizational annealing at 1200°C leads to its complete disappearance, which corresponds to the state diagram [4]. In explosive loading, more m-phase is formed from the equilibrium t-ZrO2 (i.e., the preliminarily annealed material) than from the quenched t'-ZrO2 (Fig. 1). The material with added Al2O3 is completely stable with respect to t' → m transition; no monoclinic phase is observed even after explosive loading three and five times. This is in complete agreement with concepts regarding the stabilizing influence of the domain boundaries of the quenched t'-phase and on the locking of these boundaries by Al2O3 glass phase. It was noted in [1] that t'-ZrO2 with added Al2O3 does not crystallize on annealing at 1000°C for 1 h, whereas in the absence of Al2O3 such annealing leads to total recrystallization.

The width of the tetragonal-ZrO2 line is analyzed mainly on the basis of the (111)t line, since it is not distorted by a doublet structure (Fig. 2). The width of the B (111) line may be assumed to characterize the total energy stored in the material during both plasmochemical synthesis and the subsequent explosive loading. The energy is stored by the material as domain-boundary energy and as the energy of crystal-lattice deformation within the individual domains. In the present case, it is difficult to distinguish the influence of structural dispersity and microdeformation on account of the tetragonality of the lattice and hence the doublet structure of the lines. Relatively reliable graphical isolation of the component of the doublet (311)-(113) (2θ = 60.5°) is only possible for t-ZrO2, which has been subjected to recrystallizational annealing, since its line is half as wide as that of quenched t-ZrO2. Its initial linewidth is found to be due entirely to the size of the coherent-scattering region, which is increased to 600 Å on recrystallization. After explosive loading, the dispersity changes almost threefold and becomes comparable with the characteristic dimension of the structural element of t'-phase (Fig. 3). Explosive loading also leads to microdeformation of the crystal lattice Δa/a = 1.5·10^{-3}; this value is typical for pulsed treatment of the given intensity in most ceramic powders [7].

The width of the t'-ZrO2 line before and after explosive loading is due totally to the dispersity of the structure, although this result is less conclusive and the presence of microdeformation cannot be ruled out. Against the background of the considerable broadening due to very small regions of coherent scattering (D = 120-180 Å; Fig. 3), the relatively small broadening due to microdeformation cannot be determined; the complication of the diffraction pattern due to tetragonality does not help here.