Ever-increasing demands are being made by industry for heat- and thermal-fatigue-resistant materials capable of withstanding the action of various gaseous atmospheres, chemically active liquids, and molten materials. Frantsevich [1] recommends that carbides should be used as the base of superheat-resistant alloys. However, he also notes that carbides possess little capacity for relaxation, which is responsible for their high sensitivity to stress concentration and, consequently, low resistance to thermal shock. Because of this, in the development of carbide-containing structural materials it is necessary to explore ways of improving the ductility of their carbide phase and increasing its stress relaxation capacity.

Artificial graphite, a material possessing very high thermal shock resistance, is today specified for an increasing number of high-temperature applications. Because of its comparatively low mechanical strength, inadequate oxidation resistance, appreciable gas and moisture permeability, and low abrasion and wear resistance, however, artificial graphite is unsuitable for certain types of service. To overcome these drawbacks, graphite may be employed as the base of composite materials.

In this article, the results are presented of an investigation into the physicomechanical properties of graphite-zirconium carbides and graphite-zirconium carbide-zirconium composite materials of varying chemical compositions and structures. The phase compositions of these composites are listed in Table 1. TsG-25 type composites (Fig. 1a and b) consist of two - graphite and carbide (or metal-carbide) - continuous and intertwined skeletons. TsG-50 type composites have a carbide (or metal-carbide) matrix with a graphite phase distributed in it (Fig. 1c and d).

Tresvyatskii [2], studying the effect of structure on the strength of polycrystalline brittle materials, proposed a method of classification for such materials based on the relative strengths of their filler and binder phases (U_f and U_b, respectively) and the adhesion between these phases (U_a). For TsG-50 type materials, having a carbide phase matrix, the following relation is likely to hold:

$$U_a < U_f < U_b.$$  (1)

Thus, in accordance with [2], such a composite material would be expected to fail through the formation of microcracks in the binder phase (zirconium carbide), the orientation of the cracks being tangential to the filler grain surfaces. As long as the condition U_a < U_f is satisfied, the strength of the material is independent of the strength of the filler.

No experimental data are available upon the mutual adhesion of zirconium carbide and graphite, but it is reasonable to assume that the following relation is applicable:

$$U_f < U_a < U_b.$$
Fig. 1. Microstructures of composite materials, ×100: a) TsG-25; b) TsG-25Ts; c) TsG-50; d) TsG-50Ts.

Fig. 2. Specimens for determination of strength properties: a) in tension; b) in bending; c) in compression. (All dimensions in millimeters, $R =$ radius, $\phi =$ diameter.)

graphite phase grains should have no effect on the magnitude of thermal stresses. Yet with increase in the volume fraction of the carbide phase, the elastic radial stresses in the interlayers decrease, while the axial and circumferential stresses in the matrix (graphite) grow. In the case under consideration, the most dangerous is the increase in the circumferential stresses, since these act in regions adjacent to the carbide/graphite interfaces, i.e., in zones of the weakest strength link.

One of the factors influencing the strength properties of both composite powder metallurgical materials and graphite is residual porosity. The effect of pores on mechanical properties manifests itself not only in a reduction in the effective specimen cross section. As pores change in shape from spheroids to channels and slits, their stress-raising action becomes more and more pronounced.

Thus, on the basis of earlier investigations, it may be concluded that the strength characteristics of composite materials depend on their structure, the strength of the component phases, the adhesion at the interfaces, the volume fractions and coefficients of thermal expansion of the phases, and the amount and shape of residual pores.