STRENGTHENING PHOSPHATE FOAM-CERAMICS WITH FILAMENT CRYSTALS OF SILICON CARBIDE

B. V. Shchetanov, V. N. Prilenskii, L. A. Lapidovskaya, A. I. Chernyak, and I. V. Romanovich

Foam-ceramic materials based on phosphate bonding agents have high thermal conductivity and a high melting temperature. This is why they are promising for use as heat-protecting materials. However, the important disadvantages of such materials which limit their use include their low thermal stability, low impact strength, and low strength. The theoretical and experimental studies [1-3] showed that reinforced ceramic materials with a small amount of a high-strength fiber can significantly improve the resistance of the ceramic to thermal shock and mechanical loads. It was also shown in [4] that in this case the strength characteristics of the material are also improved. The increase in strength of the ceramic is the result of the fibers impeding the spread of cracks in the matrix and thus increasing the work of destruction.

Attempts have therefore been made to improve the properties of phosphate foam-ceramics by reinforcing the ceramic with filament crystals of silicon carbide having an average diameter of 0.35 μm and an average length of 0.1 mm; these fibers have high elastic and strength parameters (modulus of elasticity, 40,000 kgf/mm²; breaking strength, 1000 kgf/mm²). It was observed that the addition to the composition of even small quantities (2.4% by volume) of SiC filament crystals makes it possible to increase the impact strength and heat resistance of the foam-ceramic.

The present paper deals with the effect of additions of SiC filament crystals on the bend-resistance of a phosphate ceramic as well as the problem of the applicability of the proposed strengthening mechanism [4] to a foam-ceramic composition.

According to [4], the strength $\sigma_c$ of a brittle composition reinforced by fibers is determined as follows:

$$\sigma_c = \sigma_m \frac{E_c}{E_m},$$

(1)

where $\sigma_m$ and $E_m$ are the strength and modulus of elasticity of the matrix, respectively, and $E_c$ is the modulus of elasticity of the composition. The strength of the matrix in the presence of reinforcing fibers is associated with the strength of the nonreinforced matrix $\sigma_{m0}$ by the relationship $\sigma_m = \sigma_{m0} \sqrt{1 + \gamma_f/\gamma_0}$, where $\gamma_0$ is the work of destruction of a nonreinforced matrix and $\gamma_f$ is the contribution of the fibers to the work of destruction of the matrix.

Since the modulus of elasticity and the strength of a ceramic are strongly dependent on its porosity, the change in these properties with the addition of filament crystals must be considered for a constant porosity of the material. Therefore, first we constructed graphs of the dependence of the properties of a phosphate-bonding-based foam-ceramic on the porosity (Fig. 1). From these we then determined the dependences of the moduli of elasticity and the strength characteristics on the volume fraction of filament crystal (Fig. 2).

The experimental results indicate that the modulus of elasticity and the bend strength of the composite foam-ceramic are degraded by an increase in porosity but are improved by an increase in the volume concentration of reinforced fibers. The addition of 12.3% SiC filament crystals to the foam-ceramic composition makes it possible to double the bend strength of the material.

According to [4], the modulus of elasticity of the composition reinforced with fibers of finite length depends linearly on the volume fraction of the fibers:

$$E_c = E_m \left[ 1 + V_f \left( \frac{E_f}{E_m} n_0 n_1 - 1 \right) \right].$$

(2)

Fig. 1. The dependence of the modulus of elasticity (a) and the ultimate bend strength (b) of a foam-ceramic composite material on the porosity: a - Δ) phosphate bonding; ▲) phosphate bonding + 2.4% filament crystal; ○) phosphate bonding + 4.7% filament crystal; ●) phosphate bonding + 9.1% filament crystal; ○) phosphate bonding + 12.3% filament crystal; b - ▲) 0% filament crystal; △) 2.4% filament crystal; ○) 4.7% filament crystal; □) 9.1% filament crystal; Δ) 12.3% filament crystal.

In this case $E_f$ and $V_f$ are the modulus of elasticity and the volume fraction of fibers; $n_0$ is the coefficient which allows for the orientation of the fibers; and $n_1$ is the coefficient which allows for the use of fibers when the matrix is loaded to the limit:

$$n_1 = \frac{l}{2l_1} \quad \text{for} \quad l < l_1; \quad n_1 = 1 - \frac{l_1}{2l} \quad \text{for} \quad l > l_1,$$

where $l$ is the length of a fiber and $l_1$ is the critical length determined from the condition $l_1 = \frac{d(\sigma_m E_f/2 \tau)}{2}$ (d is the diameter of the fiber and $\tau$ is the shear strength of the fiber-matrix bond).

Because of the complexity of the subject of our study, $\tau$ cannot be determined experimentally, and therefore, its value was estimated. According to [5], $\tau$ does not depend on the material of the fiber in the case of most ceramic systems and $\tau \approx \frac{1}{4} \sigma_{\text{bend}}$. In our case, for a porosity of 0.5, $\tau$ was assumed to be 15 kgf/cm².

Assuming that $\sigma_m/\tau = 4$, $E_f = 40,000$ kgf/mm², $E_m = 1,000$ kgf/mm², and $d = 0.35$ μm, we obtain $l_1 = 28$ μm. In our case, $l \gg l_1$ and $n_1 \approx 1$. In the case of a random distribution of fibers, $n_0 \approx 1/3$. Equation (2) can then be rewritten as

$$E_e = E_m \left[ 1 + V_f \left( \frac{1}{3} \frac{E_f}{E_m} - 1 \right) \right].$$