The article is devoted to developing ceramic composite materials with fiber reinforcement, features of their failure, and the possibility of improving mechanical properties. The state of the technology is considered for producing composite materials. Information is presented about the level of mechanical properties of ceramic composite materials including crack resistance. On the basis of the concepts of fracture mechanics processes are discussed for energy dissipation during crack propagation and also possible mechanisms for retarding cracks. The future is considered for use of composite materials with ceramic matrices in various fields of technology.

Ceramics are promising materials for the preparation of machine components and mechanisms intended for operating under conditions of high temperatures and corrosive media, and for creating a new generation of technology including engines with high fuel efficiency and economy. The limitations on using ceramics are connected mainly with their brittleness. Since the brittleness of ceramics is due to features of interatomic reaction, then in developing ceramic structural materials the main attention is devoted to improving resistance to brittle failure (crack resistance) by realizing different processes of failure energy dissipation (scattering) in the area of a crack tip making it difficult for it to propagate in a brittle body.

The most effective method for increasing crack resistance is formation of a composite structure. Introduction of a second (strengthening) phase into the structure of a ceramic may provide occurrence of processes which make crack propagation difficult (microcracking of the matrix and phase transformations in a dispersed phase, initiation by a stress field at a crack tip in the so-called "process zone;" reorientation of a crack with respect to the direction of external load operation as a result of reaction of the crack front with different barriers; crack bifurcation), and also processes which lead to an increase in the expenditure of force in overcoming friction, for example, in extracting fibers of a reinforcing phase from a matrix. In cermet composite materials it is possible to accomplish processes of energy dissipation for external forces by plastic deformation of the metal phase in the process zone. In order to realize these mechanisms the state and structure of the interface of the matrix and second phase is of particular importance.

Ceramic composite materials may have a structure with dispersed strengthening phases, with interpenetrating frameworks of two or more phases, with discrete or continuous reinforcement, with randomly orientated unidirectional fibers, and with flat or three-dimensional reinforcing elements.

Reinforcing Elements. In order to reinforce various ceramic matrices fibers or silicon carbide filamentary crystals which exhibit unique properties are mainly used. The possibility of industrial production of these crystals from a cheap natural raw material, for example, waste from rice processing, makes it possible to reduce their cost considerably. In addition ceramic matrices are reinforced with filamentary crystals of silicon nitride, titanium carbide, nitride, oxide, and solid solutions based on them, and with crystals of silicon oxynitride, aluminum nitride, and a number of other refractory compounds.

In order to improve the mechanical properties and preparation of additional qualitative characteristics (e.g., high wear resistance apart from crack resistance), combined reinforcement is used, for example, by introducing into an oxide matrix apart from silicon carbide...
filamentary crystals dispersed particles of refractory compounds (carbides, nitrides, oxides of transition metals and rare-earth elements). Combined introduction of a dispersed phase of partly stabilized zirconium dioxide and silicon carbide filamentary crystals makes it possible to achieve the additive effects of an increase in crack resistance.

In choosing a reinforcing phase not only the level of mechanical properties is considered, but also the cost of the composite material, and the possibility of using waste-free production for manufacturing it. For example, apart from silicon carbide filamentary crystals in an aluminum oxide matrix, finely-dispersed SiC powders are added, i.e., a subsidiary product in the production of filamentary crystals.

Silicon carbide filamentary crystals are used most extensively as a discrete reinforcing component of ceramic composite materials and currently they are obtained by VLS-synthesis using catalysts or high-temperature pyrolysis of rice processing wastes. The $\beta$-modification of silicon carbide filamentary crystals obtained by VLC-synthesis has a strength in tension (determined by surface compression of specimens) of more than $10^3$ (up to $30\cdot10^3$) N/mm$^2$. The thickness of the crystals may vary.

The highest crack resistance is exhibited by composite ceramic materials reinforced with continuous fibers, with unidirectional or cross-over type reinforcement, and with flat or three-dimensional reinforcing elements. Silicon carbide (silicon oxycarbide) or carbide fibers with barrier coatings and reinforcing elements are used for reinforcement.

Continuous silicon carbide fibers are obtained by chemical deposition from the vapor phase (the CVD-process) on a substrate (core). Monofilament fibers of silicon carbide may be prepared by deposition on heated tungsten or carbon fiber substrates from gas mixtures of dichloromethyl silane and hydrogen. Another technology for preparing ceramic fibers is based on pyrolysis of polymer fibers. Research in this direction started with questions of preparing carbon fibers from polycrylonitrile and mesophase pitches. In order to prepare fibers which also contain such elements as silicon, titanium, and carbon, organometallic polymers are used as starting materials. An advantage of the technology based on pyrolysis of polymers is the simplicity of preparing the original highly pure polymer fibers (by purifying polymer raw material using well-known chemical processes), and also formation of fibers at lower temperatures than with other technologies.

Processes have been developed for preparing fibers in the systems Si-C-O, Si-C-N-O, and Si-N-O. They are prepared by multistage technology including synthesis of organosilicon thermoplastic polymer drawn out into a fiber in the liquid condition, polymerization and hardening of the polymer, and pyrolysis at 1100-1400°C in an inert atmosphere. Here one of the main questions is selection of the original polymer. In order to prepare silicon oxycarbide fibers use is made of carbosilane, and fibers in the system Si-Ti-C-O may be prepared from polytitanium carbosilanes.

Carbon fibers have $\sigma_T \geq 3.5$ kN/mm$^2$ and $E \approx 300$ kN/mm$^2$, and silicon carbide fibers of the Nikalon type have up to 2.7 and 190 kN/mm$^2$, respectively. However, in spite of the high level of mechanical properties carbon fibers weaken sharply at temperatures above $-400^\circ$C in air and in view of this they are hardly used for reinforcing ceramic oxide matrices without special protection from oxidation. Silicon carbide fibers weaken under the same conditions starting from $-900^\circ$C [1].

Bases of the Technology for Preparing Ceramic Composite Materials. The technology for preparing ceramic composite materials reinforced with discrete fibers, filamentary crystals, and (or) dispersed particles involves in the general case several stages: treatment of the original components, i.e., chemical heat treatment (oxidation, reduction, nitriding, etc.), crushing, deagglomeration, dispersion, etc.; mixing of the original components in order to obtain uniform mixtures; preparation of mixtures for forming (for example, granulating); formation and preparation of the final product by sintering under pressure or without application of pressure (multistage processes are possible). Selection of the optimum version of the production process depends on the composition of the composite.

One of the most important production operations is uniform distribution of the strengthening phase in the matrix of the composite material since mechanical properties depend on the degree of uniformity. For example, deagglomeration of filamentary crystals is carried out by treatment in liquid media: water, butanol, hexanol, ethanol, including use of defloculants. In order to obtain uniform aqueous suspensions it is necessary to provide the re-