FABRICATION OF HIGH-DENSITY QUARTZ CERAMICS: RESEARCH AND PRACTICAL ASPECTS.
PART 6. A COMPREHENSIVE STUDY OF THE PROPERTIES OF BN-MODIFIED DENSELY SINTERED CERAMICS

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STRENGHT AND ELASTIC PROPERTIES OF BN-MODIFIED QUARTZ CERAMICS

At present, the ever-increasing requirements placed on the components of quartz ceramics necessitate the study of material properties characterized by rather large number of parameters. The material properties should preferably be studied and tested under conditions best suited to simulate the actual conditions of aircraft employment. The behavior of a material under extreme conditions makes it possible to determine the range of its applicability in engineering components to ensure their reliable performance.

Applicability of a structural material is primarily determined by the material’s strength properties. In our tests, the bending strength $\sigma_b$ was measured on an MRS-500 testing machine using a three-point bending scheme; the compressive strength $\sigma_{comp}$ was measured on a PSU-10 press in conformance with Russian Standard GOST 5458–75.

An essential feature of the BN-doped ceramic is its sufficiently high strength achieved at the early sintering stage. Sintered at a temperature of about 1100°C, the material shows $\sigma_b$ up to 20 MPa, whereas in undoped ceramics it was 2.0 – 3.0 MPa. With increase in sintering temperature the material undergoes rapid densification, the effective cross-sectional area of the specimen increases, the framework gains in bond strength, and at sintering temperatures of 1250 – 1275°C, the bending strength $\sigma_b$ reaches a maximum of 60 – 70 MPa.

The densely sintered ceramic with 0.5 – 1.0 wt.% BN added shows no decrease in strength, whereas densification degrades the strength properties of addition-free ceramic (Fig. 1), which suggests the occurrence of cristobalite. This

Fig. 1. Bending strength $\sigma_b$ of quartz ceramics plotted as a function of porosity $P$: 1 – 5) ceramics with 0.5 wt.% BN added; 6) undoped ceramic; 1) initial porosity 12.3%; 2, 6) 26.5%; 3) 31.3%; 4) 39.0%; 5) 46%.


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Results of a study of densely sintered quartz ceramics under conditions best suited to simulate the performance of aircraft in flight are reported. The materials studied can find application in the design of aircraft components exposed to high temperature, intense heat flow, and severe climate change.
distinctive feature is most pronounced in sintered ceramics with high initial porosity. Thus, the addition-free ceramic (initial porosity 26%; see Fig. 1, curve 6) has lower strength as compared with the BN-doped ceramic (curve 2); in the former, because of crystallization a sharp decrease in strength is observed on further densification.

The bending strength $\sigma_b$ of quartz ceramics doped with 0.5 – 1.0 wt.% BN was measured in a temperature range of 20 – 1200°C. Relevant results are shown in Fig. 2. An explanation of the behavior observed should be sought in structural properties of the material. The quartz ceramic is an amorphous substance, it consists of individual grains of sintered glass. Glass lacks a clearly defined temperature for the occurrence of plastic deformation. In quartz glass and ceramics, transition from the solid state to a liquid manifests itself as a continuous decrease in viscosity with temperature; therefore the observed increase in strength may be related to effects associated with the viscous flow of the material. This results in a lesser stress and a higher strength. Above 900°C, the material exhibits a slightly pronounced creep, which is seen in strain versus load diagrams of the specimens tested. The bending strength $\sigma_b$ was measured on specimens tested at 1200°C and different loading rates. At a loading rate of 3.6 mm/min (at which the tests were normally conducted), the bending strength was measured to be 140 MPa; an examination of the fractured specimens revealed a significant amount of strain in them. As the loading rate was raised to 37 mm/min, the test specimens experienced brittle fracture, with their $\sigma_b$ not exceeding 45 MPa. Thus, under creep conditions at the same temperature, the material can exhibit either a brittle or a viscous behavior depending on the loading rate. This high-temperature behavior is inherent in undoped quartz ceramics, which was confirmed in the literature [1, 2].

The loading rate effect was studied on an MRS-500 testing machine which allowed the rate to be varied from 0.001 to 10 mm/sec. The testing machine was equipped with a thermocryostat, which made it possible for the tests to be carried out in the temperature range from – 60 to + 400°C. At certain loading rates, the tests were conducted in duplicate; good agreement between measurement results was obtained. For comparison, the $\sigma_b$ versus loading time $\tau$ relationship (as reported in [3]) is shown in Fig. 3. It is seen in Fig. 3 that as $\tau$ increases from 15 to 1500 sec (which corresponds to a decrease in loading rate), the bending strength decreases by about 30% (a behavior typical of quartz glass); this effect is associated with exposure of the specimens to atmospheric moisture. It was shown in [3] that static fatigue was observed only when moisture was present in the surrounding medium. For example, the compressive strength $\sigma_c$ of quartz glass under dry nitrogen at 140°C was about 460 MPa; when exposed to saturated water vapor at the same temperature, the compressive strength dropped to 260 MPa [3].

At the testing temperature – 60°C, the bending strength of BN-doped ceramic showed a slight increase as compared to that at room temperature; a visible decrease was observed only in specimens subjected to long-term loading.

The increase in strength of ceramics with loading time appears to be related to the change in amount and shape of the deformed volume. Increase in loading rate typically causes the deformed state to become more nonuniform. Under conditions of long-term loading, the whole material of the test specimen with all its inherent imperfections experiences stress; as the loading rate increases, only part of the imperfections have sufficient time to contribute to the decrease in material strength.

It is seen therefore that in the design and reliability analysis of aircraft components the strength of a material should be taken with respect to the technological parameters, temperature, and loading rate. Neglect of these factors may lead to serious errors.

In poreless ceramics, the compressive strength is 500 – 600 MPa; in undoped ceramics, it is a linear function of porosity. An elasticity study of BN-doped glass ceramics at room and elevated temperatures was conducted on specimens with dimensions 10 x 10 x 120 mm using a resonance method. Relevant data are given in Table 1. As the temperature is raised from ambient to 850°C, the dynamic Young modulus shows a monotonic increase by about 9%; the shear modulus shows a monotonic decrease by 15%.