Mechanical properties of new functional composite materials based on polymeric binders

V Sh Sulaberidze¹, V D Mushenko², V A Mikheev³ and E A Skorniakova¹

¹Saint-Petersburg State University of Aerospace Instrumentation, 67, Bolshaya Morskaia str., Saint-Petersburg, 190000, RUSSIA
²OOO “Izotrop”, 28, lit. A, Belooostrovskaya street, Saint-Petersburg, 197342, RUSSIA
³AO “Nord Press”, 7, Tallinskaya street, Saint-Petersburg, 195196, RUSSIA

E-mail: elizavetasesina@mail.ru

Abstract. Composite materials which include components (binding and fillers) that provide technological and operational characteristics were investigated. As a fillers AlN, Al(OH)₃, SiO₂, CaSiO₃ powders are used. Binder – dimethylsiloxane rubber SKTN A + PMS silicone oil in 4:1 proportion. Studied composite materials are designed for dielectric coatings materials creation, which have a high thermal conductivity and do not support combustion (through the use of fillers with flame retardant properties). The results of experimental studies of the mechanical characteristics of composite materials based on siloxane binder and fillers in the form of fine powders AlN, Al(OH)₃, SiO₂, CaSiO₃ are presented. The values of strength, coefficient of elasticity, relative elongation in tensile tests, modulus of elasticity in compression tests, Shore hardness are measured.

1. Research purpose

The purpose of research was in experimental study of mechanical properties of composite materials based on siloxane binder and mineral fillers in the form of fine powders depends on it weight content in composition. As a fillers AlN, Al(OH)₃, SiO₂, CaSiO₃ powders were used. Selection of fillers related with it properties such as high values of volume electrical resistivity, high thermal conductivity (AlN), incombustibility (Al(OH)₃), high strength (SiO₂), good adhesion, which allows to use filler for anti-corrosion and sealing coatings (CaSiO₃) creation.

Also selection of fillers is related with possibility of two fillers combination creation, which allows to optimize functional properties for concrete application conditions. Powder fillers properties are studied in details and described in the literature [1 – 5]. Composite materials properties based on polymeric binder and powder fillers also studied and summarized in order of new compositions appearance [6 – 8]. Necessity of experimental study related to the fact that in the range of filler weight content from 20% to 80%, that is in “reversal of phase” area, theoretical description of properties is problematic.

Main composite materials properties are: mechanical, thermos-physical and electrical. Special properties are: incombustibility, chemical durability, humidity resistance and etc. Results of thermal conductivity studies of considered in this article materials are given by us in separate works [9, 10].
Fillers used in present studies, produced in line with requirements of regulatory documents [11, 12] and technical documents Sibelco Group (cristobalite) and ZAO GEOKOM (wollastonite).

2. Research methods and samples

Mechanical characteristics of samples were investigated on MEGEON 03000 testing machine, hardness was measured with portable hardness tester according to Shore TS-C (scales A, D). Mechanical properties are: strength (tensile strength under tension), deformation (Young's modulus in compression, Shore hardness, coefficient of elasticity in tension).

Young's modulus E is determined from the formula:

\[ E = \frac{F}{S_o} \frac{L_o}{\Delta L}, \]

where: \( F \) – tensile/ compression force applied to the sample, \( H \); \( S_o \) – cross sectional area of sample, \( m^2 \); \( L_o \) – initial length of sample, \( m \); \( \Delta L \) – change of sample length under tension (+) or compression (-), \( m \).

Relative expanded uncertainty \( U_{0.95} \) of measurement \( E \) is determined by the accuracy figure of used measuring tools of input values and amounts to 0.6% for samples of typical geometrical dimension.

Tensile strength \( P \) [MPa] is determined from the formula \( P = F/S_o \). Relative expanded uncertainty \( U_{0.95} \) of measurement \( P \) for samples of typical geometrical dimension is 0.9%.

Spring rate in tension is determined from the formula \( k = F/\Delta L \). Relative expanded uncertainty \( U_{0.95} \) of measurement \( k \) is 0.6% for samples of typical geometrical dimension.

Studies are conducted in line with requirements of regulatory documents for mechanical tests [13 – 16]. Samples for tensile test are flat plates of 40 mm length with width up to 25 mm (determined by the grip of the tension testing machine) and thickness of 1-3 mm. For binding in clamps of testing machine at the ends of the samples provided thickening (pad).

Samples for compression test are cylinders of 20 – 30 mm diameter (determined by diameter of machine upper movable platform) and length of 30 – 50 mm. According to recommendations, it is desirable that the length of the sample be less than three diameters - this allows to avoid bending the sample during compression. At the same time, the effect of friction forces in the contact “sample end – platform surface” occurs in too short samples, which leads to its non-uniform deformation - as the sample is compressed, the sample becomes barrel-shaped. Lubricants such as paraffin are used to reduce friction. In our case, there is no need for this, since the polymer binder (matrix) of the test samples has a low coefficient of friction in contact with the metal.

Materials studied in present research belong to highly elastic class – compressive loads are small and deformation where there are no noticeable deviations from Hooke's law, are significant. This distinguishes them from hard and very hard materials. Compression diagram of such highly elastic materials is fundamentally different from the compression diagrams of solid materials (there is no creep or cold flow area, etc.), and in addition, after testing, the sample length is the same as before testing, i.e. there were no residual deformation or plastic deformation area.

In compression tests, it was taken into account that for large deformations there is a significant grown up in the compressive strength due to increase of the cross-section of the compressible sample. With a small height of samples (less than 25 mm), the formation of a “barrel” was noted - the friction force between the ends of the sample and the surface of the platform did not allow the sample to compress evenly, with the result that the so-called "barrel". For estimates of the modulus of elasticity, such deformation of the sample was not allowed.

3. Results

Results of strength and elasticity characteristics measurement of investigated compositions are shown in table 1. In all cases, the binder is dimethylsiloxane rubber SKTN A + PMS silicone oil in a proportion of 4:1.
Table 1. Mechanical properties of compositions.

| Chemical combination (mineral) | Content in composition, % wt | Characteristics of powder particles | Mechanical properties of compositions with weight content of filler from 20% to 70% |
|-------------------------------|-------------------------------|-----------------------------------|----------------------------------------------------------------------------------|
|                              |                               | size, µm                          | Tensile strength, MPa | Young's modulus in compression, MPa | Shore hardness, scale A | Coefficient of elasticity, N/mm |
| AlN nitride                  | <15 (50%)                     | 3.26                              | 0.2 – 0.8            | 1.5 – 5.0                          | 15 – 45                | 1.0 – 6.0                          |
| Al(OH)₃ (305) hydroxide     | 4 – 10 up to 15               | 2.42                              | 0.2 – 0.4            | 1.0 – 3.0                          | 22 – 60                | 1.5 – 5.0                          |
| Al(OH)₃ (104) procal         | 1 – 2                         | 2.45                              | 0.15 – 1.2           | 2.0 – 6.0                          | 20 – 76                | 0.5 – 3.5                          |
| SiO₂ cristobalite            | 20 – 70                       | 2.35                              | 0.5 – 1.4            | 2.5 – 5.0                          | 20 – 75                | 1.5 – 6.0                          |
| SiO₂ quartz grade B          | <50 (82%) up to 160           | 2.65                              | 0.2 – 1.1            | 1.5 – 6.0                          | 24 – 68                | 0.7 – 5.2                          |
| CaSiO₃ (SiO₂, CaO) wollastonite | l/d=10-20 base l=12            | 2.90                              | 0.3 – 0.7            | 2.5 – 6.0                          | 28 – 64                | 0.6 – 5.0                          |

Typical dependency of strength, elasticity and hardness on the content of the filler is shown on aluminum nitride example (figures 1-3).

Figure 1. Tensile strength.

Figure 2. Young's modulus in compression.
Additional studies conducted on several batches of samples with Al(OH)$_3$ powder showed that changes in the mass content of the filler, accompanied by changes in the density of the composition by ± 20%, lead to corresponding changes in tensile strength by ± 25%. This underlines the importance of controlling the stability of the technological processes of obtaining compositions with the desired properties.

4. Conclusion
Materials with different fillers were studied in the “reversal of phase” area (from 20 to 70 wt. %), where theoretically accurate prediction of the value of the characteristic is impossible.

In general, according to obtained characteristics of strength and elasticity, materials are classified as highly elastic with the level of strength typical for similar materials. Increase of filler content in all cases led to increase of tensile strength, Young's modulus in compression and coefficient of elasticity in tension. In almost all cases dependency of characteristics on the content of the filler is not linear, but rather exponential.

Spread of characteristics values related with inhomogeneity of materials both inside one batch of samples, and in collection of samples from several batches of materials, substantially depends on accuracy of desired composition obtain. Therefore, to ensure stability of materials properties, it is necessary to control stability and reproducibility of technological process of compositions making.

References
[1] Krasny B L, Tarasovsky V P, Mosin Yu M, Krasny A B and Omarov A Yu 2013 Research of properties of aluminium hydroxide powders *Machinery and engineering education* 1 (34) pp 26-34
[2] Berlin A A 2009 *Polymer composite materials structure, properties, technology* (SPb.: Professiya) p 560
[3] Marino Xanthos 2010 *Functional fillers for plastics* (Wiley-VCH) p 462
[4] Lubin George 1988 *Handbook of Composites* (Moscow: Mashinostroenie) p 488
[5] Matthews F L and Rawlings R D 2004 *Composite materials. Engineering and science* (Moscow: Tekhmosfera) p 407
[6] Nielsen L 1978 *Mechanical properties of polymers and polymer compositions* (Moscow: Khimiya) 310 p
[7] Vishnyakov L R, Grudina T V and Kadyrov V Kh 1985 *Composite materials. Reference* (Naukova Dumka) p 592
[8] Ershova T 2013 Electronic Devices Blocks Electromagnetic Isolation. Polymer Compositional and Compound Materials *Electronics: Science, Technology, Business* 3 (125) pp 64-9
[9] Sulaberidze V Sh, Mushenko V D and Mikheev V A 2016 Thermal conductivity of heterogeneous compositions based on polymers with mineral fillers (SPb.: IPF “Renome”) p 92

[10] Sulaberidze V Sh, Mushenko V D and Mikheev V A 2018 Thermal conductivity of compositions based on a siloxane binder with a high filler content of aluminum hydroxide powder Questions of radio electronics 10 pp 39-43

[11] TU 6-09-110-75 Aluminum nitride. White

[12] TU 17-11-001-00658716-99 Aluminium hydroxide

[13] ISO 527-2:2012 Plastics. Tensile test method

[14] ISO 604:2002 Plastics. Compression test method

[15] GOST 9550-81 Plastics. Methods for determination of elasticity modulus at strength, compression and bending

[16] GOST 270-75 Rubber. Method of the determination elastic and tensile stress-strain properties