Formation and study of coatings from composite material for special electrical devices

K K Kim¹ and S N Ivanov²

¹Emperor Alexander I St. Petersburg State Transport University, 190031, Saint Petersburg, Russia
²Komsomolsk-on-Amur State University, 681013, Komsomolsk-on-Amur, Russia

E-mail: kimkk@inbox.ru

Abstract. The using of new composite coatings and materials has led both to the qualitative improvement of the operating characteristics of electrical equipment and also to the creation of encapsulated devices, their capabilities are most effective provided by composite materials with specified physical and chemical parameters. There are main results of the study of coatings based on polymer composite material in this paper.

1. Introduction
The forming of coatings from the composite materials is connected not only with the conditions of their operation but also with the possibilities of effective and high-tech using to ensure the quality characteristics of the final product. To ensure the reliability of the functional elements of electrical devices it is advisable to use the technology of winding and casting of polymer composite materials (PCM). The coating forming processes are based on various operations of processing composite materials into the products. A lot of papers [1–4] is devoted to the development of tribo-couplings based on the PCM. It lets to realize the formation and manufacture of the coating of the active elements of a special electromechanical converter (SEC) intended for the simultaneous generation and transportation of thermal energy with using polymeric composite materials. The physical-mechanical and tribotechnical properties of the used coatings were investigated for the verification of the parameters.

2. Development of forming technology
The epoxy-diane resin is used as the basic initial component for the synthesis of the PCM used to cover the active elements of the SEC. The glass fiber, fluoroplastic-4D and molybdenum disulfide form a group of modifiers [5].

The most important factors affecting on the structure and properties of the PCM are the process parameters such as temperature and pressure ensuring the uniformity of the structure, the minimum level of residual shrinkage and thermal stresses, a high degree of completeness of the curing and crystallization processes.

From the point of view of automation of technological operations of forming the injection epoxy compounds the greatest technological difficulties is caused by the mixing of pitch with excipients, dosing and mixing of a compound with a hardener in the set proportions and formation and curing of active surfaces of the SEC.
One of the common methods of manufacturing the epoxy compositions is the separate weighing of components and their further mixing. The various types of equipment are used to automate the process. For example, there are mixers collecting the mixture from the walls and bottom of the working apparatus and giving a minimum amount of air inclusions. The installations of continuous operation contain gear pumps which feed the components of the composition, they include the scales with a valve which controls the percentage of ingredients or the control valve in the line providing viscosity and pressure of the resin.

The analysis of the existing developments allows to determine the main technological operations:

– the preparation of the initial components of resin, modifiers, hardener; the preparation of the base; the mixing of epoxy resin with excipients and the preparation of the composition; the dosing of the composition and hardener;

– the mixing and feeding of the composite to form the active surface elements;

– the forming the polymer part;

– the complex of related processes of curing of the PCM, heat treatment and mechanical treatment.

To ensure the solidity of the inner part of the coating by the method of the radial winding we manufacture the inner bearing surface reinforced by the cotton fabric and impregnated along the entire length by the epoxy resin. Further the polymer coating with excipient providing the specified tribotechnical parameters is applied on it by the centrifugal method. Then we set the outer reinforced rings, we make the filling and vacuum curing at a high temperature of the ends of the formed product. This technology provides a constant structure of the anti-friction coating of the inner surface and the uniformity of thickness of the fluoro-plast and disulfide molybdenum along the whole length of the SEC. The degree of compaction and uniformity of impregnation is the controlled technological parameter in the process of forming the product by the radial winding. The methods and techniques of compaction of the excipient depend on the physical and mechanical properties of the composition and technological equipment. The permeability of the excipient affects the rate of impregnation and the productivity of the forming process. The permeability is a technological characteristic depending on the nature of the elementary components, their orientation and degree of compaction and it determines the breaking load and density.

For the composite antifriction materials the influence of the tension of the reinforcing cloth and the temperature of the curing mode on the stress level in the material requires a special study because the presence of modifiers affects on the character of the polymerization process. The improving of the optimal technological modes for various reinforcing materials allows to improve their operational properties.

To obtain the internal coating of the SEC we use the centrifugal forming technology. The centrifugal casting technology reduces the complexity of processes, reduces the duration of manufacturing parts of required sizes and ensures the high accuracy of products, significantly reduces the amount of waste at the performance of final mechanical operations required to achieve the required dimensional tolerances and cleanliness of the working surfaces.

3. Study of tribotechnical characteristics of the coating

The verification of parameters at the study of coating characteristics was carried out on the basis of the GOST 11262-2017. We measure the sizes of the detail in the break zone to determine the cross-sectional area at the axial loading of the samples. The results of measurement of tensile and compressive strength are presented in table 1.

The analysis of the results of strength measurements shows that for the modified coating the average tensile strength is about 42 MPa and for compression is 88 MPa, the tensile strength of the initial material of the matrix casting at a rotation frequency of 5 s⁻¹ is on average about 30 MPa.

The study of tribotechnical characteristics of the internal coating was carried out with the using a tribometric measuring and computing complex based on a physical friction machine in the laboratory of composite materials of the Pacific State University.
Table 1. The strength of the inner coating.

| Values                  | Sample number | Average value |
|-------------------------|---------------|---------------|
|                         | 1  | 2  | 3  | 4  | 5  |           |
| Force $F$, N            | 380| 350| 410| 370| 360| 374       |
| Area $S$, mm$^2$        | 10.41| 6.54| 11.87| 10.76| 7.31| 9.378     |
| Strain $\sigma$, MPa   | 36.5| 53.51| 34.54| 34.38| 49.42| 41.63     |
|                         |           |               |           |           |           | Compression |
| Force $F$, N            | 3470| 3180| 3260| 2700| 3750| 3272      |
| Area $S$, mm$^2$        | 38.7| 35.76| 38.90| 32.70| 41.38| 37.488    |
| Strain $\sigma$, MPa   | 89.7| 88.9| 83.8| 82.6| 90.6| 88.1       |

In the process of testing the coating with an axial load in the range of variable pressures 2.5...15 MPa and sliding speeds of 2...6 m/s we defined the tribological properties of polymer composite materials. The dependences of the coefficient of friction on the nominal pressure and sliding speed are shown in tables 2 and 3.

Table 2. The dependence of the coefficient of friction of the pressure.

| Sliding speed 2 m/s | Pressure, MPa | Coefficient of friction |
|---------------------|---------------|-------------------------|
|                     | 4  | 6  | 8  | 10 | 12 |               |
|                     | 0.100| 0.080| 0.056| 0.044| 0.038 |           |
| Sliding speed 4 m/s | Pressure, MPa | Coefficient of friction |
|                     | 4  | 6  | 8  | 10 | 12 |               |
|                     | 0.120| 0.080| 0.060| 0.042| 0.030 |           |
| Sliding speed 6 m/s | Pressure, MPa | Coefficient of friction |
|                     | 4  | 6  | 8  | 10 | 12 |               |
|                     | 0.080| 0.060| 0.041| 0.036| 0.032 |           |

![Figure 1](image1.png) (a) ![Figure 1](image2.png) (b)

Figure 1. The active converter element before (a) and after coating (b).
The obtained results show that the coefficient of friction within the pressure 2.5...15 MPa and sliding speeds of 2...6 m/s is varied from 0.03 to 0.12. Among the design parameters the load has the most significant influence on the coefficient of friction. A sample of the active element of the converter with a coating modified by PCM is shown in figure 1. This coating is manufactured in the laboratory "Composite materials" of the Pacific State University [5–9].

Table 3. The dependence of friction coefficient on sliding speed.

| Sliding speed, m/s | Pressure 5 MPa | Pressure 7.5 MPa | Pressure 10 MPa | Pressure 12 MPa |
|-------------------|----------------|-------------------|----------------|----------------|
|                   | 2              | 3                 | 4              | 5              | 6              |
| Coefficient of    | 0.086          | 0.084             | 0.082          | 0.075          | 0.065          |
| friction          |                |                   |                |                |                |
|                   | 2              | 3                 | 4              | 5              | 6              |
| Coefficient of    | 0.058          | 0.060             | 0.064          | 0.057          | 0.050          |
| friction          |                |                   |                |                |                |
|                   | 2              | 3                 | 4              | 5              | 6              |
| Coefficient of    | 0.046          | 0.047             | 0.049          | 0.042          | 0.038          |
| friction          |                |                   |                |                |                |
|                   | 2              | 3                 | 4              | 5              | 6              |
| Coefficient of    | 0.040          | 0.038             | 0.036          | 0.032          | 0.028          |
| friction          |                |                   |                |                |                |

4. Conclusions
The developed coating designs based on modified polymer composite materials with using centrifugal, vacuum casting and radial winding technologies and tests of their tribotechnical characteristics have shown the ability of the modified PCM to provide the low friction and wear.

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