Application of powder from alloy of brass L63, in the composition of elastomeric composite, for increasing the tension sensitivity coefficient

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Abstract. The range of rubber-cord products used in industry is quite wide. Their design includes determination of parameters during calculation and subsequent tests confirming their reliability, operability and properties. It is equally important to assess the stress-strain state (VAT) of a structure during operation, which allows to understand the accident rate, make a timely decision, collect statistics for effective development of new structures and improvement of old ones. The VAT control methods offered today have a number of drawbacks: the short service life of measuring and sensing elements, their introduction of errors in the operation of the structure, and often the inability to measure; for example, when working in aggressive media. The aim of the work is to evaluate the possibility of using brass powder L63, obtained by high-speed processing, in the elastomeric composite. To achieve the set goal it is necessary to solve the following problems: to make samples from the mixture with the addition of powder L63 and without it; to compare the samples from the received mixtures on the strain-sensitivity coefficient; to compare the samples from the specified mixtures in the process of mechanical loading on the breaking machine with simultaneous registration of electrical resistance. The results: Studies were conducted on the possibility of using ultra-dispersive powder L63 to improve the electrical properties of rubber. It has allowed to increase the coefficient of strain-sensitivity in 5-7 (in comparison with classical electroconductive rubbers), keeping their mechanical properties. Sensitive elements made of such a rubber mixture will give an opportunity to create “smart” composites, as well as to control the stress-strain state. Based on the results of these studies, the Act of Implementation has been issued.

1. Introduction
The work on self-testing of products is widely conducted by various tire companies and research centers [3]. The presence of electronic devices (sensors, microchips) on the wheel rim in the inner cavity of the tire or in its tread allows to obtain information about the state of the tire, which is transmitted to a computer located in the car (figure 1) [6, 7, 8, 9].
Continental is working on a system that will inform the vehicle driver of the presence of ice, snow or water on the road based on a tire temperature and deformation analysis. Pirelli has also made some progress towards creating smart tires. The authors of publications [1, 10, 11, 12, 13, 14] speak about the use of electrically conductive rubber with stable strain sensitivity (electrically conductive rubber is a material with specific electrical resistance less than \(10^5\, \text{Ом} \times \text{м}\)). It will allow to exclude influence of such sensitive element on properties of a product (tires) as their materials are close in properties and durability. The specific electrical resistance of electrically conductive rubbers depends on the type of rubber and the quantity of the filler, which are: carbon particles (graphite, soot), carbon nanotubes and metal powders. The article reviews the results of the study of electrically conductive rubber obtained using a certain technology. Besides, the scheme of one of variants of installation of a sensitive element from such rubber in the bus (figure 2) is shown.

![Figure 1. Sensor buses (1) and receiver (2).](image1)

![Figure 2. Scheme of element installation in the bus.](image2)

Such sensors should have a high strain sensitivity coefficient, a wide range of operating temperatures, have little influence on the product characteristics, and experience large deformations without destruction.

2. Problem formulation
The concept of strain sensitivity is related to the measurement of the deformation force generated by the application of strain gauges, which in turn is based on the strain effect of... It consists of the dependence of the electrical resistance of a metal conductor on its mechanical deformation. The specified effect is characterized by an output signal, depending on the relative change of resistance of the strain gauge \(\Delta R/R\). Here, \(R\) is the electrical resistance of the conductor before deformation and \(\Delta R\) is its increase after deformation.
The ratio $\Delta R/R$ to the relative strain that caused it $\varepsilon$ at some, constants, values of current, temperature and other factors is called the coefficient of strain sensitivity of the K resistor. That is, the value of the strain-sensitivity coefficient is equal:

$$K = \frac{\Delta R}{R \varepsilon}.$$ (1)

This ratio is true for relative deformations not exceeding $5 \cdot 10^{-3}$. Strain-sensitivity coefficient is a dimensionless value\footnote{4, 5}. It cannot be measured, but only determined indirectly, by the dependence given above.

The author of this work within the framework of the scientific project № 16-38-00706 "Development of the scheme of the automated operational control of the stress-strain state of the elastomeric composite in the composition of the rubber-cord product" was offered to use brass UDP L63 produced by high-speed processing as an additive to the applied fillers.

The aim of the work is to evaluate the possibility of using brass powder L63, obtained by high-speed processing, in the elastomeric composite.

The following tasks need to be completed in order to achieve the objective:

1. Make samples from a mixture with and without the addition of powder L63;
2. Compare the samples from the obtained mixtures by the strain-sensitivity coefficient;
3. To compare samples from the specified mixtures during mechanical loading on the rupture machine with simultaneous registration of electrical resistance.

3. Theory

The sensor was made of conductive rubber as in the publication\footnote{1}. The following requirements were set for the powder: the particle size of the applied powder should lie in the interval from 1 μm to 50 μm and the third party impurities should not be more than 3% of the initial chemical composition (GOST 15527 – 2004\footnote{2}).

Fifteen rubber electroconductive compositions have been developed for research. Six of them provided for the addition of electrically conductive carbon, grades СН85 and СН210, and three of the remaining six compositions - the addition of ultradisperse powder L63. The first six mixtures are a classic version of electrically conductive rubber, based on a combination of carbon grades with good physical, mechanical and electrical properties. No specific formulations are given as they are subject to the intellectual property of the project № 16-38-00706.

In order to compare mixtures with and without the addition of powder L63, an assessment of the coefficient of strain sensitivity of each composition was made. The samples made of the above mixtures were mechanically loaded on the rupture machine "Tensometer T2020-DC10" with simultaneous registration of electrical resistance. The value of the electrical resistance was calculated from the voltages measured with the spectrum analyzer ZET 017-U2, according to dependence:

$$R = R_o \cdot \left( \frac{U_{out}}{U_1} - 1 \right).$$ (2)

where $R$ – the electrical resistance of the sample;
$R_o$ – the internal resistance of the input channel ZET 017-U2, equal to 99 kOhm;
$U_{out}$ – voltage at the analyser output;
$U_1$ – voltage on the first channel of the analyser.

Briefly summarize the main technical characteristics of the used measuring instruments. The Tensiometer T2020 Breaking Machine is used to measure force and strain during static testing of material samples under tensile or compression conditions. The material used is polymers and rubber. The structure of the strain gauge consists of the following blocks (see figure 3): a base with a fixed moving crosshead frame; force transducer; clamps for fixing samples; extensometer; computer.

The movable crosshead is moved along column guides using screw pairs. The force sensor is mounted on the crosshead. One clamp is connected to the base, the other to a force transducer. A strain gauge converts the force applied to a sample and the strain it tests into electrical signals. They are fed into the electronic control unit located at the base. The computer software enables automatic measurement and recording of results in a convenient way (tables, graphs).
Figure 3. Appearance of the Tensometer T2020-DC10.

The characteristics of the strain gauge (metrological and technical) ensure the necessary level of accuracy of measurements. Thus, the limits of the permissible error of force and strain measurement are as follows ±1 %. The appearance of the dual-channel portable signal spectrum analyzer (model ZET 017-U2) is shown in figure 4.

Figure 4. Appearance of the analyser ZET 017-U2.

Spectrum analyzers ZET 017-U2 are registered in the State Register of Measurement Instruments for № 39236-08. The analyzer, which has a graphical control and display interface, has the following capabilities: signal analysis (real-time and previously recorded); narrowband spectral analysis of signals; voltage measurement (DC and AC); generation of sinusoidal and DC signals.

The use of analyzers may be stand-alone or as part of the measuring systems required for the research (e.g. status diagnosis, monitoring, regulation of parameters, etc.). Metrological characteristics of ZET 017-U2 analyzer in two modes of operation are given in table 1, where the following designations are accepted: PCU – programmable gain; Uizm – measured input voltage level, mV.
Table 1. Analyzer metrological characteristics ZET 017-U2.

| Mode | PCU | Characteristics |
|------|-----|-----------------|
|      |     | Measured AC input voltage range |
|      | 1   | between 0.0007 to 7 V |
|      | 10  | between 0.07 to 700 mV |
|      | 100 | between 0.007 to 70 mV |

"AC Voltmeter."

|        | 1   | ± (0.005U_{izm} + 10) mV |
|--------|-----|--------------------------|
|        | 10  | ± (0.005U_{izm} + 1) mV  |
|        | 100 | ± (0.005U_{izm} + 0.1) mV |

Absolute measurement error tolerance limit
input voltage in the frequency range from 3 Hz to 20 kHz

Measured DC input voltage range

| Mode | PCU | Characteristics |
|------|-----|-----------------|
|      | 1   | ±10 V |
|      | 10  | ±1000 mV |
|      | 100 | ±100 mV |

"DC Voltmeter."

Absolute measurement error tolerance limit
DC input voltage

| Mode | PCU | Characteristics |
|------|-----|-----------------|
|      | 1   | ± (0.005U_{izm} + 50) mV; indicator mode |
|      | 10  | ± (0.005U_{izm} + 5) mV; indicator mode |
|      | 100 | ± (0.005U_{izm} + 0.5) mV; indicator mode |

4. Experimental results
The characteristic type of dependence of electrical resistance of the sample on the value of its deformation (at small and large deformations), obtained in the course of the study, is shown in figure 5 [1].
5. Discussion of results
Analyzing the type of curves, we can say that the dependence is almost linear to the degree of deformation of the sample, equal to about 30%. At further increase in deformation is visible curve fracture, indicating a rapid increase in the coefficient of strain sensitivity of rubber. Work on the scientific project is continuing, but already on the basis of the results of the study it can be concluded that it is possible to use the resulting ultra-dispersed powder to improve the electrical properties of rubber. It has allowed to increase the coefficient of strain-sensitivity in 5...7 (in comparison with classical electroconductive rubbers), keeping their physical and mechanical properties. Sensitive elements made of such a rubber mixture will give an opportunity to create "smart" composites, as well as to control the stress-strain state.

6. Conclusions
The following conclusions were drawn from the work:
1. Research on the possibility of using ultra-dispersive powder L63 to improve the electrical properties of rubber has been conducted. It has allowed to increase the coefficient of strain sensitivity in 5...7 (in comparison with classical electroconductive rubbers), keeping their mechanical properties.
2. Sensitive elements made of such a rubber mixture will give an opportunity to create "smart" composites, as well as to control the stress-strain state. Based on the results of these studies, the Act of Implementation has been issued.

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