Physical Sciences and Technology. Vol. 9 (No. 3-4), 2022: 83-88

IRSTI 55.03.11 https://doi.org/10.26577/phst.2022.v9.i2.010

Thermophysical characteristics of friction materials based on bronze with 12% tin with the addition of GK-1 graphite powder and foundry coke

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(Received 2 December 2022; received in revised form 22 December; accepted 29 December 2022)

The results of measurements of thermal properties in the temperature range from 20 °C to 100 °C of bronze with 12% tin obtained by powder metallurgy and 30 vol. % carbon-containing additive in the form of powders of graphite grade GK-1 (7-10 microns), foundry coke (less than 63 microns). The specific heat capacity of the samples was measured using the differential scanning calorimetry method. Thermal diffusivity and thermal conductivity were studied by two different methods. In the first case, the thermal diffusivity is determined by the laser flash method and the thermal conductivity by the calculation method. In the second case, the coefficients of thermal diffusivity and thermal conductivity were measured by the flat heat source method. It has been established that 30 vol.% of graphite powder GK-1 in the composition of bronze with 12% tin makes it possible to obtain the value of the thermal conductivity coefficient equal to 23,97 W/(m·K) at 20 °C with its further increase to 25,65 W/(m·K) at 100 °C. The specific heat capacity is 376,71 J/(kg·K) at 20°C and 399,26 J/(kg·K) at 100 °C. The addition of 30 vol.% coke powder makes it possible to obtain a thermal conductivity coefficient equal to 9,03 W/(m·K) at 20 ° C and 10,76 W/(m·K) at 100 °C. The specific heat capacity ranges from 391,80 J/(kg·K) at 20 °C to 413,57 J/(kg·K) at 100 °C.

Keywords: differential scanning calorimetry, laser flash method, hot disk method, heat capacity, thermal diffusivity, thermal conductivity, friction materials, powder metallurgy.
PACS number: 66.70.Df.

1 Introduction

One of the main directions in the development of mechanical engineering is the creation of elements with high performance, reliability and service life. Modern industry puts forward new requirements for the creation of new materials and minimization of the dimensions of units and mechanisms of machines, as well as the improvement of their manufacturing technologies. Powder metallurgy is one of the advanced technologies that makes it possible to implement efficient production, reduce labor costs, re-duce the number of technological operations and create materials with unique properties. Such products, due to their performance indicators, are widely used in automotive and tractor mechanism and special-purpose equipment [1-7].

Friction powder materials based on tin bronze are often used for lubricated friction conditions. They have high wear resistance, thermal conductivity, corrosion resistance, however, during operation they do not provide a high and stable value of the friction coefficient, which is necessary for efficient and stable operation of the friction assembly. Thermo-physical characteristics also affect the efficiency of the friction material, determine its ability to remove heat and work under increased load-speed conditions, the duration of slipping [8-13].

The improvement of properties is possible due to the creation of a heterogeneous structure, through the use of additives of various compositions [14, 15]. The purpose of this study is to determine the temperature dependences of the coefficients of thermal diffusivity, thermal conductivity and specific heat capacity of a friction material based on bronze with 12% tin and 30 vol.% of carbon-containing additives in the form of graphite powder of the GC-1 brand with a fraction of 7-10 microns (composition 1), and foundry coke powder with a fraction of less than 63 microns (composition 2).

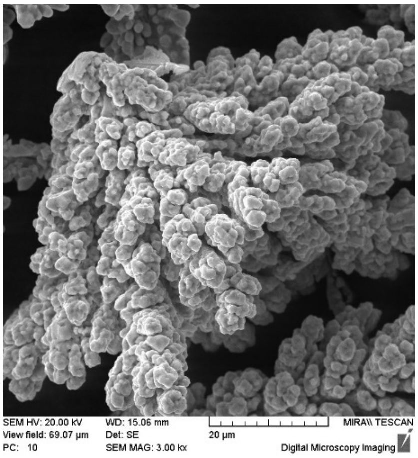
2 Experimental part

2.1 Manufacturing technology and sample preparation

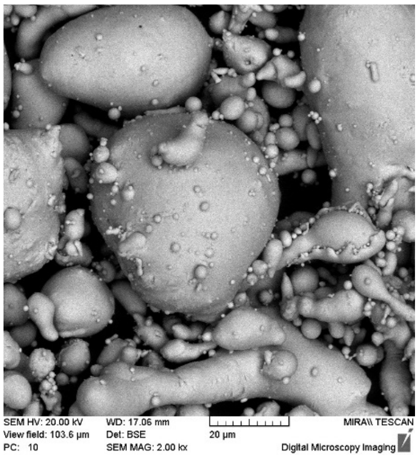
The charge of the friction material was obtained by mixing in a paddle mixer powders of copper grade PMS-1 with an average particle size of 80 μm (Fig. 1, a), tin grade PO 1 with an average particle size of 30 μm (Fig. 1, b), graphite grade GK-1 (Fig. 1, c), foundry coke (Fig. 1, d). Mixing time was 45 min. Then the mixture of initial powders was pressed in technological equipment, which made it possible to obtain samples in the form of a disk with a diameter of 25 ± 0,5 mm and a thickness of 2,5 ± 0,5 mm. The resulting samples were sintered in a protectively reducing atmosphere of dissociated ammonia at a temperature of 840 °C for 50 min. The appearance of the samples is shown in Fig. 2, a.

Similarly, samples were prepared for measuring the heat capacity by differential scanning calorimetry. The geometric dimensions of the samples did not exceed 4 mm, the masses of the samples were m_{comp1} = 25,81 mg, m_{comp2} = 47,22 mg (Fig. 2b).

A sample of bronze (CuSn12) was also prepared without the addition of a carbonaceous additive. It was used to assess the influence of alloying components on the values of thermophysical characteristics.



a)



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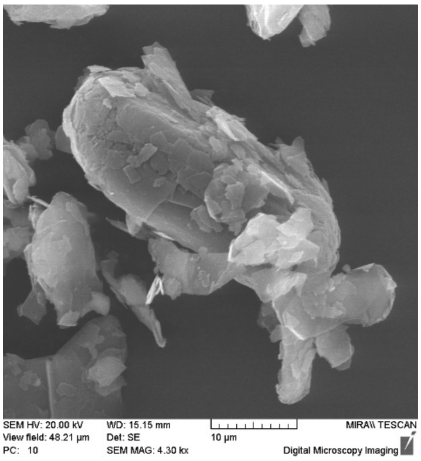

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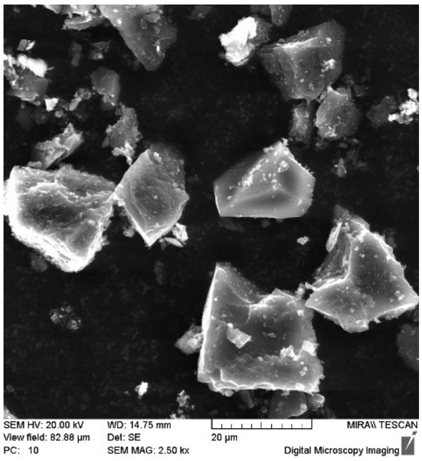

d)

Figure 1 – The shape of the particles of the initial powders used to obtain the friction material: a) PMS-1; b) PO-1; c) GK-1; d) foundry coke

a) b)

Figure 2 – Appearance of samples for thermophysical testing:
a) samples after manufacturing; b) samples for DSC method

2.2 Experimental technique

The thermophysical characteristics of the samples were measured by two methods.

In the first case, the thermal conductivity coefficient λ of the samples was determined by calculation via the ratio:

$$\lambda = \alpha \cdot c \cdot \rho \quad (1)$$

where *a* is the coefficient of thermal diffusivity; *c* is the specific heat capacity; ρ is the density.

The thermal diffusivity was determined by the laser flash method on an LFA 457 Microflash installation (Netzsch, Germany). The essence of the method is heating one side of the sample with a laser pulse and recording the temperature change on its opposite surface [16]. The measurements were carried out in the temperature range from 20 °C to 100 °C with a step of 20 °C. To increase the absorbency of the material, a thin layer of graphite was deposited on the end surfaces of the samples.

The specific heat capacity was measured on a DSC 204 Phoenix F1 (Netzsch, Germany) installation using differential scanning calorimetry (DSC), which is based on determining the difference in heat fluxes between the test sample and a thermally inert substance (standard) at the same time [17, 18]. The experiment was carried out in the temperature range from 20 °C to 100 °C with a step of 1 °C in the mode of monotonous heating. The heating rate was 10 K/min. Nitrogen gas was used as purge and shield gas at a flow rate of 20 and 50 ml/min, respectively.

The density of the samples was determined by hydrostatic weighing and amounted to ρ_{comp1} = 6142 kg/m^3 and ρ_{comp2} = 5259 kg/m^3.

In the second case, to determine the thermophysical characteristics of the samples, a Hot Disk TPS 2500S thermal constant analyzer (Sweden) was used, which is based on the nonstationary method of a flat heat source (hot disk method) [19, 20]. In this method, a sensor in the form of a double helix was located between the two samples under study, which simultaneously performed the function of both a temperature recording sensor (resistance thermometer) and a source of heat flow. During the experiment, 200 measurements of the electrical resistance of the sensor were performed, and then a function of the change in the temperature of the test sample was built. Based on the analysis of the constructed function, the thermal conductivity and thermal diffusivity of the test sample were determined.

Sensor 7577 F1 with a radius of 2 mm was used in the experiment. Electric power from 200 mW to 300 mW was supplied to it (depending on the material of the samples and their temperature). The time of the experiment was 1 s. Measurements were made in the temperature range from 20 °C to 100 °C with a step of 20 °C.

3 Results and discussion

CuSn12 bronze sample without a carbon-containing additive was studied only at room temperature. Its density was 7106 kg/m^3, and its thermal conductivity was 28 W/(m·K). This value of thermal conductivity corresponds to earlier studies of porous bronze materials [21].

Figures 3-5 show the dependences of the thermophysical characteristics of the materials under study on temperature.

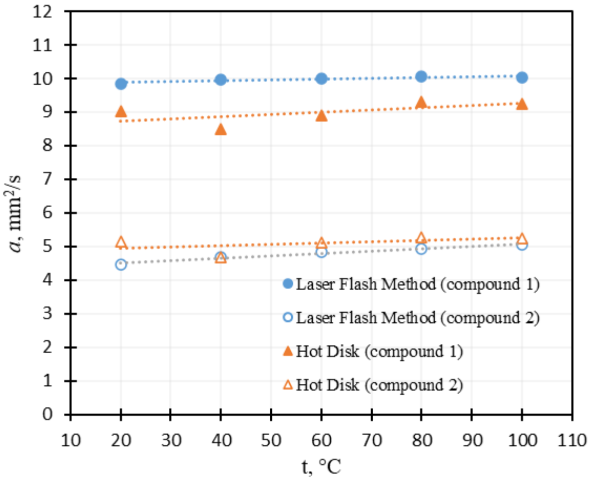

Figure 3 – Dependence of the thermal diffusivity of samples on temperature

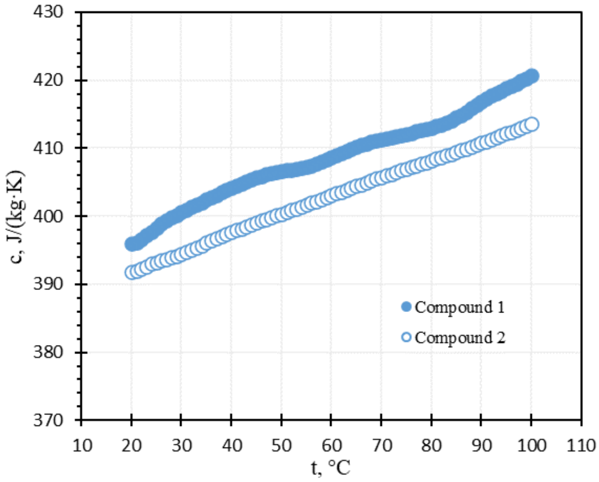

Figure 4 – Dependence of specific heat capacity of samples on temperature

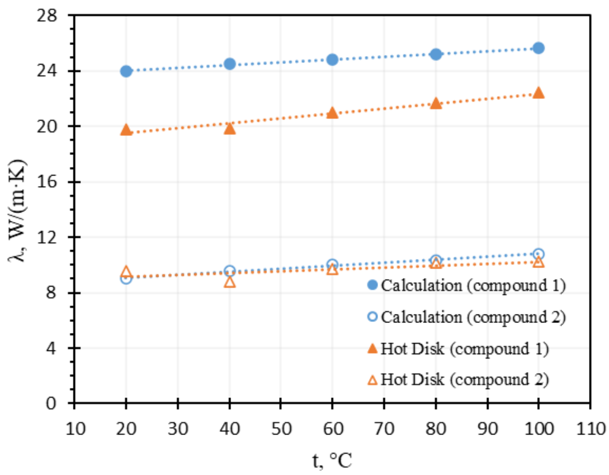

Figure 5 – Dependence of thermal conductivity coefficient of samples on temperature

It can be seen from the graphs that for the studied materials, with increasing temperature, there is a slight increase in thermophysical characteristics, which is typical for metal alloys of bronze. However, the high value of the thermal conductivity of the introduced component did not lead to an increase in the thermal conductivity of the final composition. The thermal conductivity of samples with a carbon-containing additive is lower than the thermal conductivity of pure bronze, the value of which at room temperature is ~28 W/(m·K). This is due to a significant decrease in the density of the material, due to the introduction of a lighter component as an additive. The content of 30 vol.% carbon-containing additive led to a decrease in the density of the final composition by 13% with the addition of GK-1 grade graphite and by 25% with the addition of foundry coke. It is possible that a decrease in the percentage of graphite will lead to an increase in the thermal characteristics of the final composition. This issue requires further research.

In addition to the density of materials, the difference in the values of the thermal conductivity coefficient between the studied materials is explained by the difference in the properties of their additives. The graphite with a crystalline structure used in composition 1 has a higher thermal conductivity value compared to foundry coke powder having an amorphous structure.

4 Conclusions

The paper presents the results of measurements of the thermophysical characteristics of bronze with 12% tin, obtained by powder metallurgy, and 30 vol. % carbon-containing additive in the form of powders of graphite grade GK 1 with a fraction of 7-10 microns, foundry coke with a fraction of less than 63 microns.

It has been established that 30 vol.% of GK-1 graphite powder in the composition of bronze with 12% tin makes it possible to obtain a thermal conductivity value equal to 23,97 W/(m·K) at 20 °C with its further increase to 25,65 W /(m·K) at 100 °C. The specific heat capacity value is 376,71 J/(kg·K) at 20°C and 399,26 J/(kg·K) at 100°C.

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Funded by Al-Farabi KazNU