High-temperature installation for testing composite ceramic materials on the friction and wear behaviour

M N Roshchin
Mechanical Engineering Research Institute of the Russian Academy of Sciences, 4, M.Kharitonyevskiy Pereulok, Moscow, 101990, Russia

E-mail: roschin50@yandex.ru

Abstract. The paper considers the design of a high-temperature testing unit for testing composite ceramic materials on the friction and wear behaviour. The friction mode of the samples is provided according to the finger scheme in the temperature range of 20 - 1000ºС under the conditions of the normal load range of 35 - 300N. Linear speed, in terms of rotational motion, when testing samples is 0.05-0.37 m/s.

1. Introduction
The operating capacity of friction units at high temperatures is ensured by the use of new materials and structural solutions. The prospects for creating high-temperature friction units are largely associated with the use of new composite materials, tested under operating conditions or at test benches. To ensure the friction unit operating capacity during testing, it is necessary to establish conditions close to real. That, in turn, entails the design of special equipment, the development of special experimental techniques [1, 2].

When choosing a test scheme, it is necessary to evaluate the possibility of reproducing the loaded condition on the model friction unit, which occurs in the full-scale friction unit, mode of motion, and also the temperature regime. The temperature regime is largely determined by the coefficient of mutual overlap (i.e. the ratio of the nominal areas where the friction process is carried out on the contacting samples), which determines the distribution of heat flows [3].

The industry produces a sufficiently large range of testing machines for testing on tribological properties. However, it was found that for testing composite materials at high temperatures, those test schemes that are implemented on these testing machines are not suitable. To ensure the testing of composite materials when heating a friction pair to a temperature of 800ºC, it is necessary to thoroughly refine the design of the testing machine.

2. The purpose of work
The purpose of the work is to design a testing unit for testing materials at high temperatures according to the disk-finger friction scheme: axially loaded; when registering the heating temperature of the test samples; velocity of friction surfaces; friction moment measurements; wear of friction surfaces.

For high-temperature tests, a scheme was chosen when the contact of the friction occurs on the nominal area, the disk-finger. The face contact of the rotating surface of the samples and the fixed disk is used to implement the method for assessing frictional heat resistance, namely, that the fixed and rotating surfaces of the samples are pressed against each other by a given axial force and stepwise
increase the temperature, axial load and rotational speed of the movable sample. At each stage of axial loading, heating of the test samples, and the moving speeds of the friction surfaces, the friction moment under given conditions and the wear of the friction surfaces are measured [4,5].

Testing of material samples should be carried out under conditions simulating the work operation of a full-scale friction unit [6]. Therefore, the most acceptable method of tribological testing of materials is the disk-finger scheme, because test bench test results are easier to extend to other schemes and unit sizes. The design of the bench should provide reliable operation with repeated use [7].

3. Equipment and materials

For tribological tests, the VTMT-1000 high-temperature bench was designed and manufactured, which provides the friction regime of samples according to the finger scheme in the temperature range of 20–1000°C under the normal load range of 35–300 N [8]. Taking into account thermal insulating, the heating unit allows one to heat the test samples to a temperature of 1000°C. The linear velocity, under conditions of rotational motion, during testing of the samples was 0.05-0.37 m/s. Figure 1 presents a diagram of the test installation VTMT-1000.

![Diagram of the test installation VTMT-1000](image)

The test bench unit consists of a lower disk 1 made of steel 40X13 where test samples 2 are installed, which are mounted in the upper clamping disk 3. An axial force P is applied to the upper disk; the disk receives rotation V from the drive 4, the speed of which is regulated by the frequency converter 5. The test samples with the lower and upper disks are located on the furnace platform 14. Furnace heating is provided by heating elements 6 connected to a power regulator 7. The temperature monitoring of the lower disk and the furnace platform is carried out using thermocouple elements 9 and 10 connected to the switch 12. Drive shaft measurement is carried out by sensor 11 followed by signal output to the switch. The assembly 1, 2, 14 has axial mobility in the swivel block 16 in the form of an axial rolling bearing, which is equipped with a cooling device for running water. A lever 15 is installed on the furnace body, which bears on a force measuring device 8 connected to the switch and
a computer 13 for recording the results of frictional torque measurements of the samples and control temperature readings, and the speed of the experiment.

Figure 2 shows the upper clamping disc with the samples located. Figure 3 presents the location of the test samples on the lower heated disc.

The test bench is made on the basis of the drilling machine model 2A125, on which the test assembly and temperature and friction torque monitoring devices are located. The mechanism of loading the test samples with an axial force P and the drive to ensure a given relative rotational motion V of the test samples are used from a drilling machine. To adjust the speed, the speed control 5 is used.

The axial load on the test samples is applied by creating a load moment on the movable upstanding spindle of the machine. The axial force is calibrated on the test samples using the exemplary portable dynamometer DOSM-3-2U 5095 (GOST 9500-84) installed on the base of the machine, in which the movable spindle rests. The response threshold of the dynamometer is not more than 0.02% of the maximum measurement limit, the value of the smallest scale division is not less than 0.1%. During the tests, the frictional torque was measured. To do this, a lever is installed on the furnace body, resting against the tension sensor. When the upper sample holder rotates, the moment of resistance to rotation with the lever is transmitted to the tension sensor. Friction moment and temperature are recorded using strain gauges ZET 7111 Tensometer CAN. Data is transmitted digitally via CAN 2.0 using the Modbus protocol. USB +CAN ZET 717 interface converter is designed to connect measuring networks based on intelligent transmitters and control ZETSENSOR modules with CAN to PC interface. Measurement accuracy is of at least 1% of the largest measurement limit. The moment of rotation resistance was recorded continuously and is stored in the memory of the device [9].

During testing, the temperature is continuously monitored in the lower heated disk 1, in the heating platform 10. The temperature of the lower steel sample (heated to the set temperature) was measured using a chromel-alumel thermocouple recorded on the device using temperature sensors ZET 7120 TermoTC-CAN. The control range when using a TXA sensor at 1200°C, resolution 1°C, the limit of permissible basic measurement error of the input parameter (excluding sensor error) is 0.5%. Duplication of the temperature readings was carried out according to the readings of the single-channel universal digital device A565-001-02, which works in conjunction with thermoelectric converters according to GOST 6616-86 when measuring temperatures up to 1300°C. Accuracy class
0.1/0.06, resolution 0.1°C. The temperature of the heating platform was measured with a digital temperature meter ATT-2000, dual-channel, with a K type thermocouple (NiCr-NiAl).

The samples were tested under conditions of rotational motion with a constant angular velocity. The installation drive is powered by an asynchronous electric motor. The setting of the set rotation speed is provided by changing the current frequency using the INNOVERT ISD mini frequency converter having an output frequency range of 0.1 - 400 Hz, and an accuracy of indicating the output frequency of 0.1 Hz [10].

4. Methods of processing the results of the experiments

The design of the bench involves continuous registration of the antitorque moment during friction of the test samples on steel, namely, the strain gauge records the force oscillograph chart applied to the lever. Figure 4 shows a sample oscillograph chart recorded at load, MPa: 0.22; 0.3; 0.5; 0.67; 1.0.

Figure 4. The force oscillograph chart on the lever timed at load: 1- 0.22MPa; 2- load replacement zone; 3-0.3MPa; 4-0.5MPa; 5-0.67MPa; 6-1.0MPa.

5. Conclusions

A high-temperature testing unit for testing composite ceramic materials on the friction and wear behaviour has been designed. The friction mode of the samples is provided according to the finger scheme in the temperature range of 20 - 1000°C under the conditions of the normal load range of 35 - 300N. Linear speed, in terms of rotational motion, during testing of samples is 0.05-0.37 m/s.

References

[1] Alisin V V, Roshchin M N and Lukyanov A I 2019 Development and research of friction units operating at high temperatures as applied to spacecraft Vestnik NPO named after S.A.Lavochkin 1 61-5

[2] Adrien P Gillard, Guillaume Couégnat Sylvain Chupin and Gerard L Vignoles 2019 Modeling of the non-linear mechanical and thermomechanical behavior of 3D carbon/carbon composites based on internal interfaces Carbon 154 178-91
[3] Grib V V and Lazarev G E 1968 Laboratory tests of materials on the friction and wear behaviour (Moscow:Nauka) p 141

[4] Machine parts 2007 ed O A Ryakhovskiy (Moscow:MSTU) p 520

[5] Vildeman V E and Tretyakov M P 2013 Tests of materials with the construction of complete strain diagrams J.of Machinery Manufacture and Reliability 2 93-8

[6] Trukhanov V M 2013 Prediction of the resource of parts, assemblies, mechanisms and the technical object as a whole at the design stage J.of Machinery Manufacture and Reliability 3 38-42

[7] Pavlov I V 2015 The lower-bound estimate of reliability based on the results of accelerated tests J.of Machinery Manufacture and Reliability 44(3) 257-62

[8] Alisin V V and Roshchin M N 2019 Tribology of carbon-containing materials at high temperatures J.of Physics:Conf.Series 1399(2019) 044034 2018

[9] Roshchin M N 2018 The effect of temperature and load on coefficient of friction CCCM-steel at high temperatures J. of Advanced Research in Technical Science (North Charleston, USA: SRC MS, CreateSpace) 10(1) 21-4

[10] Severov P B and Dumanskii A M 2014 Experimental studies on mechanical behavior of carbon fiber laminates under static and cyclic loading J. of Machinery Manufacture and Reliability 43(5) 435-8