Experimental study on the influence of temperature on the wear performance of polymer sliding plate materials for bridge bearings

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Abstract: The wear performance of polymer sliding plate material for bridge bearing is the key factor affecting the durability of bearing sliding unit. Based on the selection of friction pairs commonly used in bridge bearings in China, the wear performance of modified polytetrafluoroethylene (PTFE) and ultra-high molecular weight polyethylene (UHMWPE) plate, which are gradually used in engineering in recent years, is tested and studied in this paper. It is hoped to provide reference for the engineers and researchers engaged in related work in China.

1. Introduction

Bridge bearing is an important part of various types of bridge structure. It is located between the bridge and the pad stone, connecting the upper structure and the lower structure of the bridge, coordinating the deformation of the two parts, and ensuring the smooth transmission of the load on the upper part of the bridge. In the process of bridge operation, due to the impact of vehicle load, temperature load, wind load and seismic load, the relative displacement will occur between the upper structure and the lower structure of the bridge. If these relative displacements cannot be removed by the slide of bridge bearings, or the friction force generated by sliding is too large, it will cause immeasurable damage to the bridge structure, and in serious cases, it may lead to structural damage.

In the structural composition of bridge bearing, the device used to generate relative sliding to remove the displacement load between upper and lower structures is called sliding element. Based on different design concepts and functional requirements, bridge bearings have a variety of types and structural characteristics. The commonly used bearing types in the world include plate type elastomeric pad bearing, pot bearing, spherical bearing, roller bearing, etc. However, no matter which type of bearing, the sliding unit mainly includes the steel plate, which is made of stainless steel plate or austenitic steel, and the sliding plate composed of polymer material or composite material.

In China, stainless steel plate is used for steel plate in most cases. Polytetrafluoroethylene (PTFE) is often used as the sliding plate in the early stage. In recent years, modified polytetrafluoroethylene (MPTFE) and ultra-high molecular weight polyethylene (UHMWPE) materials have been gradually applied.
In general, it is considered that the MPTFE and UHMWPE have higher compressive strength, better self-lubricating property and better wear resistance. However, these conclusions are obtained under constant test temperature. In practical application environment, the influence of material temperature change caused by bearing sliding on wear resistance cannot be ignored, especially for long-span cable stayed bridge or steel bridge system. For these types of bridges, the sliding displacement amplitude is large, the sliding frequency is high, and the friction heat generation will greatly reduce the wear resistance. The reason is that the lower softening temperature of the material may lead to permanent thermoplastic deformation in the process of temperature rise caused by friction, resulting in surface damage of sliding plate material and affecting the wear performance of sliding plate.

At present, there is a lack of research on the wear properties of polymer slide materials in China. Therefore, in order to study the influence of temperature rise on the wear performance of polymer sliding plate materials, the author designed the comparative test of wear performance of modified polytetrafluoroethylene and ultra-high molecular weight polyethylene provided by different manufacturers under the natural temperature environment in the laboratory.

2. Test device and test method

2.1. Test device
The test was carried out in the State Key Laboratory of Bridge Engineering Structural Dynamics in Chongqing, and the loading was carried out by a small high-speed compression shear testing machine designed by the laboratory. The small high-speed compression shear testing machine used in the test consists of two actuators, which work as vertical loading and horizontal loading respectively (see Figure 1 and Figure 2). The vertical loading component is a hydraulic actuator with a rated load of 1500KN, and the horizontal loading component is a hydraulic actuator with a rated load of 250kN. Both actuators have the capacity of displacement control and load control loading, and can realize the loading of displacement time history spectrum and load time history spectrum. In order to ensure the lateral loading stiffness of the structure, the horizontal loading actuator and horizontal support members are fixed on the rigid shear wall, and the horizontal displacement movement is constrained by the guide rail (Figure 1).
Figure 1. Schematic diagram of small high speed compression shear testing machine

Figure 2. Photo of loading device of small high speed compression shear testing machine
2.2. Test methods and samples

In this study, the test method of wear performance of modified polytetrafluoroethylene (MPTFE) and ultra-high molecular weight polyethylene (UHMWPE) sliding plate materials was optimized based on Chinese transportation industry standard “JT/T 901-2014 Bridge bearing polymer materials” and European standard "EN1337-2:2000 structural bearing ground part 2: sliding element", the test method takes into account the following factors:

1. The double shear test method is used to carry out the wear performance test. The test of two friction pairs is carried out each time. The average value of the two friction pair tests is taken as the experimental results for the calculation of friction coefficient and wear rate.

2. Vertical loading is controlled by load. The load value is calculated according to the effective area of the test piece, and the control compressive stress is 45MPa; Horizontal loading is controlled by displacement, the displacement loading waveform is sine wave, the amplitude is ± 20mm, and the loading speed is controlled according to the average linear speed of 10mm / s.

3. The total loading distance of the test is 2000m, that is to say, 25000 loading cycles are carried out. The vertical load, horizontal load and temperature of stainless steel plate are recorded every 40m to analyze the temperature change of sliding plate material and the change of friction coefficient of the sliding unit during the test.

4. In order to study the temperature rise caused by friction and the influence of material's thermoplastic on the wear performance of the material, the temperature of friction pair is not controlled during the loading process, but the ambient temperature is controlled within 20 ± 3 ℃.

The products of two manufacturers of modified polytetrafluoroethylene and ultra-high molecular weight polyethylene slide plate materials were selected. The modified polytetrafluoroethylene material numbers were G1 and G2, and the ultra-high molecular weight polyethylene slide plate material numbers were C1 and C2. The nominal diameter of the sample is 160mm, and the thickness is obtained according to the manufacturer's original sample test. During the test, the stainless steel plate will not be replaced, but the wear condition of the stainless steel plate shall be checked after each test. If there is no abnormality, the stainless steel surface is cleaned with acetone and reused after drying. See Table 1 for details of test samples.

Table 1. Basic information of test samples

| Material No. | sample No. | effective friction area (mm²) | thickness (mm) | material density (kg / m³) |
|--------------|------------|--------------------------------|----------------|--------------------------|
| G1           | G1-1       | 15180                          | 7.852          | 2040.                   |
|              | G1-2       | 15180                          | 7.836          |                          |
| G2           | G2-1       | 14601                          | 8.020          | 2090                    |
|              | G2-2       | 14601                          | 8.026          |                          |
| C1           | C1-1       | 15205                          | 8.165          | 940                     |
|              | C1-2       | 15205                          | 8.105          |                          |
| C2           | C2-1       | 15482                          | 7.940          | 960                     |
|              | C2-2       | 15482                          | 7.985          |                          |

3. Test results and analysis

3.1. temperature change curve of stainless steel plate during the test

Both modified polytetrafluoroethylene (MPTFE) and ultra-high molecular weight polyethylene (UHMWPE) are high molecular materials, and they are thermoplastic materials. It is generally believed that the wear of sliding plate materials consists of adhesive wear and fatigue wear, and the temperature of materials has a direct impact on these two.

In the process of the test, the slide material is always in the state of high stress and motion, so it is very difficult to directly measure its temperature change. As a metal material, stainless steel plate has
good thermal conductivity. Therefore, the temperature change of the specific position of stainless steel plate is measured by the temperature sensor installed on the edge of stainless steel slide plate in this experiment. The temperature change of stainless steel plate reflects the temperature change of sliding plate material in the test process. The temperature changes of four groups of stainless steel plates during the test are shown in Figure 3.

![Figure 3. Temperature curve of stainless steel plate during the test](image)

It can be seen from Figure 3 that the temperature of stainless steel plate increases with the increase of friction distance. Except material G1 corresponding to steel plate temperature rise is more obvious, the other three materials corresponding to stainless steel plate temperature rise is relatively gentle.

3.2. Variation curve of friction coefficient of test piece during the test

The friction coefficient of sliding element is a direct index to reflect its performance, and the friction coefficient also directly affects the wear performance of sliding plate material. In the process of wear test, the changes of four groups of sliding units with sliding distance are shown in Figure 4.

![Figure 4. Temperature curve of stainless steel plate during the test](image)

It can be seen from Figure 4 that the change trend is consistent with that of stainless steel plate: with the increase of friction distance, the friction coefficient of sliding unit also shows an increasing trend. Similarly, except for material G1, the friction coefficient of the other three materials increases gently.

3.3. Inspection of sample condition after test

After the test loading is completed, the sample condition is checked (Figure 5 to Figure 8) in order to
confirm the influence of temperature change and friction coefficient change on sliding plate material.

According to the sample state after the test, the material G1 with obvious temperature change during the test is seriously worn, and obvious indentation can be seen on the sliding plate itself, and the friction trace of other materials is not obvious, and there is no obvious indentation.
3.4. Calculation of wear rate of sliding plate material

According to the calculation formula of line wear rate in Appendix B of "JT/T 901-2014 Bridge Bearing Polymer Materials", the line wear rate of various sliding plate materials is calculated and listed in Table 2.

| Material No. | Sample No. | Line wear rate of sample (μm/km) | Line wear rate of material (μm/km) |
|--------------|------------|----------------------------------|-----------------------------------|
| G1           | G1-1       | 17.94                            | 18.07                             |
|              | G1-2       | 18.20                            |                                    |
| G2           | G2-1       | 3.77                             | 3.33                              |
|              | G2-2       | 2.88                             |                                    |
| C1           | C1-1       | 4.93                             | 4.78                              |
|              | C1-2       | 4.62                             |                                    |
| C2           | C2-1       | 10.13                            | 9.87                              |
|              | C2-2       | 9.62                             |                                    |

4. Conclusions and suggestions

4.1. Effect of temperature on Wear Properties of polymer slide plate materials

The quantitative indexes of wear performance of polymer sliding plate materials include linear wear rate and friction coefficient. By comparing the experimental data of different materials, it is found that the temperature rise of stainless steel plate has an important impact on the friction coefficient and linear wear rate of sliding plate materials. In the process of the experiment, the temperature change curve of the slide material itself was not measured, but the temperature change of the stainless steel plate directly reflected the temperature change of the material under the same conditions. The relevant test results are listed in Table 3.

| Sliding plate material | Stainless steel plate temperature rise | Average friction coefficient of sliding unit | Line wear rate of material (μm/km) |
|------------------------|----------------------------------------|---------------------------------------------|-----------------------------------|
| MPTFT G1               | 16.8                                   | 0.02583                                     | 18.07                             |
| MPTFT G2               | 6.8                                    | 0.00586                                     | 3.33                              |
| UHMWPE C1              | 5.3                                    | 0.00783                                     | 4.78                              |
| UHMWPE C2              | 4.4                                    | 0.00907                                     | 9.87                              |

Data analysis in Table 3 shows that:

1) For the four materials tested, the higher the average friction coefficient is, the higher the final wear rate is. The increase of friction coefficient is mainly due to the plastic deformation after the temperature rise;

2) During the test, the heat generated by friction causes the temperature rise of sliding plate material, which significantly affects the wear performance of the material. Because the polymer materials studied are all thermoplastic materials, under high pressure (45MPa), the plastic deformation of slide plate material is caused by the rise of material temperature, which significantly increases the friction coefficient and linear wear rate of sliding plate material, and may lead to the loss of function of sliding plate material.

4.2. Suggestions

From the experimental results of this paper, due to the thermoplastic characteristics of polymer materials, the working temperature has a significant impact on the properties of polymer slide materials. At the same time, the bridge bearing is in the field working environment, and its working
temperature varies greatly with different regions and seasons. Therefore, the influence of temperature on friction coefficient and wear resistance of sliding plate material should be fully considered in the test and engineering application.

1) It is suggested that the thermoplastic properties should be considered as an important factor in the selection of sliding plate materials for bridge bearings;

2) It is suggested that the thermal plasticity evaluation index of sliding plate material should be added in the test specification of sliding plate material for bridge bearing.

3) In the evaluation of bearing sliding unit wear performance test, it is suggested to determine the time history curve of environmental temperature in the process of wear test according to the climate conditions of the bridge area, so as to better match with the actual working conditions of the bridge, and the experimental data is more scientific and reliable.

4) In the high temperature area, the ventilation and heat dissipation measures of sliding plate material should be considered in the structural design for the high frequency and large displacement bearing design.

References

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