Sliding Bearing Material Testing Machine under High Temperature Corrosion Conditions

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Abstract. Sliding bearings are widely used in submerged rolls of strip galvanizing line immersed in zinc bath. Submerged roller bearing pair materials include sleeves and bushings. These two parts are in high temperature, load and corrosive working environment. They are prone to wear and failure. The service life of bearing pair materials determines the operation time of the whole galvanizing line. In order to ensure long-term operation of galvanizing line, the most ideal method at present is to select suitable sleeve and bushing material matching pairs. To screen sleeve and bushing materials with good matching performance, a friction and wear tester simulating sleeve and bushing materials in high temperature molten zinc environment was designed and developed. The test machine is divided into three parts: driving system, loading system and heating system. The driving system drives the sample rotation of the sleeve; the loading system drives the bushing pattern to load the sample of the sleeve; the well heating furnace heats the zinc ingot to 480 °C to simulate the zinc pool environment; the vertical loading of bearing pattern and sleeve pattern, the alignment and insulation of the driving system and the loading system are comprehensively considered and solved. The stability of the test machine under test conditions is analyzed to ensure that the signal collected by the sensor has a high reference value.

1. Introduction

To solve the problem of surface corrosion of steel plate and to protect the surface of steel plate better, hot-dip galvanizing process of steel plate emerged as the times require. It has been more than 80 years since the appearance of hot-dip galvanizing production line in the 1930s. Generally speaking, galvanizing line can be divided into hot-dip pure zinc (GI) and its alloyed products (GA), which are widely used in automobile steel plate production in Japan, Europe and the United States [1-2]. The principle of hot-dip galvanizing anticorrosion relies on a dense layer of zinc liquid plated on the surface of the steel plate, so that the steel plate is completely separated from the external electrolytes and other substances, thus effectively avoiding corrosion of the steel plate. When the surface of the coating is not very dense, the external electrolyte, the zinc plated on the surface of the steel plate and the iron plated on the surface of the steel plate naturally form the primary battery. In this primary cell, zinc is the anode and iron is the cathode, so zinc is gradually dissolved, but iron is protected. Generally, the corrosion life of steel sheet after hot-dip galvanizing will be increased to about 10-25 times.

Figure 1.1 is a schematic diagram of the galvanized sheet production line. The sinking roll is located in the Zinc Bath. Figure 1.2 is a schematic diagram of the sinking roll working in the zinc pool.
The temperature of the zinc pool is 480 degrees. Sleeves and bushings are common consumables in the process of galvanizing strip steel. On the one hand, due to the load received by the sinking roll passing through; the axle sleeve acting on the bushing at both ends causes higher contact stress, and because the actual speed of the sinking roll of galvanizing line is not high, the liquid zinc is difficult to form hydrodynamic lubrication, and the contact fatigue between the bearing and the axle sleeve is very easy to occur; on the other hand, the bushing and the axle sleeve are all positioned. In high temperature molten zinc solution, it receives strong corrosion, which inevitably leads to chemical reactions and accelerates the failure of sleeves and bushings.

**Figure 1.1** Galvanized sheet production line

**Figure 1.2** Working condition of sink roll

At present, the service life of bearing pair material in industrial galvanized line is about two weeks. Once bearing pair material fails, it is necessary to stop production line immediately and replace spare sleeve or bushing, which will bring huge economic losses. To prolong the service life of bearing pair materials in galvanizing line, the most effective method is to achieve satisfactory service life of bearing by matching contact pair materials and verifying and screening through simulation experiments. For this reason, a test machine was developed to simulate the friction and wear of bearing pairs of sink rolls in high temperature molten zinc solution.

2. Design of testing machine

Considering the actual working conditions of galvanizing line, the test machine is divided into driving part, loading part and heating part [3]. The driving part uses the frequency conversion motor to drive the sample rotation of the sleeve to simulate the rotation of the sunk roll sleeve. The loading part uses the hydraulic cylinder to simulate the bearing pressure caused by the tension of the strip, the buoyancy of zinc liquid and the gravity of the sunk roll itself in the actual working condition. In the heating part, a well-type heating crucible furnace is used to heat the zinc ingot in a graphite crucible to 480 °C, which simulates the high temperature molten zinc liquid in the galvanizing pool of the actual galvanizing line. The structure of the testing machine is shown in Figure 2.1.
2.1. Driving system

The driving system is powered by an integrated motor with frequency conversion and speed regulation. The motor shaft is connected with the torque sensor, the intermediate shaft and the testing shaft in turn through the coupling. The sample sleeve is fixed with the test shaft through bolts and rotates with the test shaft. Two copper cage deep groove ball bearings are assembled on the intermediate axle and the testing axle respectively (copper cage is adopted considering the requirement of heat insulation) and fixed in the bearing seat. All couplings use phenolic resin coupling, as shown in Figure 2.2. Thermal insulation is also considered to prevent the signal of the torque sensor from being disturbed by high temperature and the motor from burning out.

2.2. Loading system

The loading part of the loading system is a hydraulic cylinder. The outer thread of the piston rod end of the hydraulic cylinder is connected with the inner thread of one end of the pressure sensor through a connecting rod, and the other end of the pressure sensor is connected with the loading rod. In order to prevent the inclination of the loading rod in the process of loading, two guideway pedestals are designed to cooperate with the loading rod. During the loading process of the hydraulic cylinder, the test shaft of the driving system will be slightly deformed, leading to the impossibility of vertical
loading. The loading structure shown in Figure 2.3 is designed. A loading transfer part is added between the loading rod and the bushing pattern. One end of the loading transfer member is a cylinder, which can be directly inserted into the loading rod and the cylindrical end face of the loading transfer part does not contact the end face of the loading rod hole; the other end of the loading transfer part is provided with a rectangular groove. The bushing pattern can be embedded therein, and the load transfer member can be connected with the bushing pattern through the pin. The rectangular end surface of bushing pattern and the end surface of loading transfer parts with rectangular grooves leave gaps. This is due to the deformation of the testing shaft section during actual loading. The loading rod can rotate through the pin on the loading transfer member leaving room for slight rotation, ensuring vertical loading and making the test results more convincing.

Figure 2.3 (a), Loading rod components

Figure 2.3. (b) Loading rod assembly structure

2.3. Heating system
The heating system is mainly composed of well crucible heating furnace and lifting platform. During the test, zinc ingot will be put into isostatic graphite crucible, graphite crucible will be put into stainless steel inner liner, together with stainless steel inner liner and graphite crucible, into well-type high temperature heating furnace. Finally, the heating curve and holding time can be set.

After the experiment, it is necessary to separate the pattern from the zinc liquid immediately, take off the pattern, and design the lifting platform as shown in Figure 2.4. The upper end of the bench is a supporting heating furnace bench welded by angle steel. Four corners of the bench are welded with four hollow steel tubes respectively. The screw rod is penetrated into the hollow steel pipe, the furnace
is lowered to the appropriate position by the hydraulic jack at the bottom of the heating furnace, and then the screw rod and the hollow steel pipe are locked and fixed by the nut, so is the operation of the rise.

![Diagram of assembly alignment of testing machine]

**Figure 2.4.** Heating furnace lifting platform

2.4. Assembly alignment of testing machine

As shown in Figure 2.1, the bottom of the test machine is a T-groove platform, and the T-groove has a high straightness. The brackets used in the test machine are all I-beams of the same size, and the size and processing accuracy of the bottom pads are exactly the same. Therefore, the better straightness of T-groove is used to locate the bracket of driving system and loading system, so that the bracket of the two parts is completely aligned. The following steps can be taken:

- Firstly, the limit bar is threaded with the cushion block, and the limit bar is pressed into the T-groove. The matching size and tolerance are shown in Figure 2.5.
- The positioning pin is used to limit the limit bar and cushion block to ensure that the bottom of the whole testing machine is fixed.
- Taking the same side of the four pads with the same size and processing precision as the datum level, the positioning grooves of I-beam steel are set up on the four pads to ensure that the distance between the I-beam support and the datum level is the same.
- Assemble the supporting angle steel and I-beam steel, take one side of the angle steel as the datum plane, and process symmetrical positioning pin holes on the large-scale machining center to ensure that the drive system and the shafting parts of the loading system are concentric.
- Insert the I-beam bracket into the positioning groove of the cushion block, and fix it.
Through the above steps, the whole testing machine ensures higher requirements for alignment and concentricity, and the test results are more accurate. The overall assembly of the test machine is shown in Figure 2.6. The testing machine can adjust the speed, load, temperature and change the sample material. Sleeves and bushings may be made of ceramic [2-3], cobalt-based [4] and iron-based alloys [5] or coated materials [6-8], detailed material appendix is shown in Table 4.1.

**Figure 2.5** Bottom positioning assembly drawing

**Figure 2.6** Physical object of testing machine

3. Reliability analysis of testing machine

3.1. Heat transfer analysis
To prevent heat transfer from burning out sensors and other components, it is necessary to simulate and analyze the heat transfer in the front part of the sample test shaft, the sleeve and the bushing immersed in molten zinc at 500°C. The driving system is powered by an integrated motor with frequency conversion and speed regulation. The motor shaft is connected with the torque sensor, the intermediate shaft and the testing shaft in turn through the coupling. The sample sleeve is fixed with the test shaft through bolts and rotates with the test shaft. Two copper cage deep groove ball bearings are assembled on the intermediate axle and the testing axle respectively (copper cage is adopted considering the requirement of heat insulation) and fixed in the bearing seat. All couplings use phenolic resin coupling, as shown in Figure 2.2. Thermal insulation is also considered to prevent the signal of the torque sensor from being disturbed by high temperature and the motor from burning out. The heat transfer analysis of the drive system and loading system is carried out, and the results are shown in Fig. 3.1. The bearing temperature of the torque sensor is 80. The simulation results show that the temperature of the position of the torque sensor is less than 35.6°C, which shows that the torque sensor can work properly. The actual air-fired heating furnace uses infrared thermometer to measure the position and display the temperature value of 35°C (room temperature), this temperature is very close to the simulation results. Similarly, the temperature of the pressure sensor and the hydraulic cylinder in the loading system is close to the actual room temperature and can work normally.

3.2. Coupling Analysis of Thermodynamic Field

Under the dual action of high temperature and load, whether the strength of parts of loading system and driving system meets the need of test is an urgent problem to be solved. It is necessary to make corresponding analysis before experiment. All shafting components are steel by default. The results of deformation and stress distribution in the thermal field can provide reference for practical test. Firstly, load, speed and other boundary conditions are added. The overall boundary conditions are shown in Figure 3.2, in which ball bearings are replaced by equivalent constraints [9-10].
After the corresponding parameters are set, the distribution of deformation and thermal stress is solved, as shown in Fig. 3. It can be seen that in the thermal field, the maximum deformation of the shaft reaches 2 mm. In the shoulder position of the shaft near the rotating sleeve, there is a greater stress concentration, which is close to the yield limit of steel. In addition, the molten zinc at high temperature is corrosive to some extent. Considering comprehensively, the material of shaft can be replaced by Hot-Strength steel in practical test.

**Figure 3.2.** Boundary conditions of thermal stress field

**Figure 3.3.** (a) Deformation under thermal stress field
4. Conclusion
The sliding bearing material testing machine can effectively evaluate the sleeves and bushings material under high temperature, corrosion and loading conditions. The maximum temperature can be adjusted to 1200 °C, the maximum loading force can reach 1 ton, the maximum speed of the pattern can reach 600 RPM, and it is easy to replace test materials, various material combinations are shown in Table 4.1. The matching materials with superior performance can be screened out through a large number of tests.

Table 4.1. Material combinations tested in molten zinc alloy bath.

| Bushing         | Sleeve                                      |
|-----------------|---------------------------------------------|
| Stellite #6     | WC-Co coating on 316L stainless steel       |
| SiAlON          | Laser clad WC coating on 316L stainless steel|
| SiC/graphite    | Stellite #4                                 |
| Stellite #6     | Stellite #6                                 |

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