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Original Research Article

Application of Aluminum Alloy Cap in Bridge Bearings

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Abstract: In order to improve the combination form of friction pairs of existing bridge bearings and improve the durability of bridge bearings, this paper investigates the technical status and development trend of bridge spherical bearings at home and abroad, draws lessons from European standards, and puts forward a new friction pair of alloy spherical cap combination, which replaces the existing process of spherical cap coated stainless steel plate and chromium plating on the surface of spherical cap, and solves the environmental pollution, corrosion and peeling caused by chromium plating or coated stainless steelof spherical cap, the disadvantages of high line wear and easy to damage the wear plate. Through mechanical property test, line wear test andsalt spray test, the three processes are compared and analyzed, and the advantages of alloy spherical capare demonstrated. Its performance is better, the corrosion prevention is more durable, the manufacturing process is simple, and the mass production cost is low. Then the prototype is trial produced according to the standard, and the test meets the standard requirements, which further proves that the application of this technology to the bridge bearings can ensure the longer service life of the support and the safer bridge structure, This is also a new trend of market development for bridge bearings.

Keywords: Alloy spherical cap; Bridge bearing; Spherical bearing; Anodizing; Salt spray test.

1. Introduction

At present, spherical bearings are becoming increasingly popular in the field of seismic reduction and isolation in buildings and bridges. However, the selection of friction pairs in spherical steel bearings determines the overall performance of the bearings. Therefore, the design of friction pairs has become a key part of controlling the quality of spherical bearings[1]. In order to meet the requirements of low friction and high wear resistance, the domestic national standard GB/T17955-2009 stipulates that the convex spherical surface of the spherical crown liner can be coated with stainless steel plate or electroplated with hard chromium[2]. The domestic railway industry standard TB/T 3320-2013 also specifies the treatment of the spherical crown liner, requiring that the convex spherical surface of the spherical crown liner should be coated with stainless steel plate[3]. Therefore, various manufacturers choose to weld stainless steel or chrome on the steel ball crown and combine it with wear-resistant materials to form a friction pair. However, if welding stainless steel plates, the weld seam is highly susceptible to corrosion and is prone to failure under long-term load. If chrome plating is used, the chromium layer on the edge area of the chrome plated part is prone to peeling off, and chrome plating can also cause serious environmental pollution[4].

Through the study and analysis of the European standard EN1337, it was found that foreign countries can not only use coated stainless steel plates and surface electroplated hard chromium for the treatment of ball crown lining plates, but also use aluminum alloy materials[5,6]. However, there is no research on this technology in China, so this article will conduct research on aluminum alloys.

2. Technical Route

Referring to the European standard aluminum based alloy material, combined with domestic spherical bearing specifications and processing technology, select an aluminum alloy material with suitable performance

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requirements for sample trial production. Through mechanical performance testing, wear testing, and salt spray testing of aluminum alloy samples, the material performance is verified. Then, according to the requirements of bridge bearing standards, aluminum alloy ball caps are made and used on spherical bearings. Vertical bearing capacity, rotational performance, and friction coefficient tests are conducted on the finished bearings to verify whether the aluminum alloy ball cap bearings meet the domestic TB/T3320 standard.

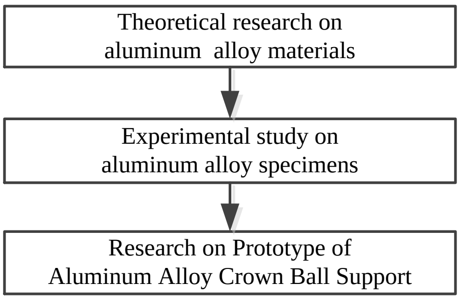

Figure 1 Technical roadmap for the research of aluminum alloy spherical crown spherical supports.

3. Theoretical Research on Aluminum Alloy Materials

3.1 Introduction to Support Friction Pairs

The friction pair of the support is the main component of the spherical steel support, which achieves normal rotation of the support through the spherical metal sphere and wear-resistant plate, and evenly transfers the upper load to the lower structure through the sphere[1]. Chromium plating or stainless steel coating are often used for ball crowns to reduce friction coefficient, increase hardness, and reduce wear.

If the convex spherical surface of the crown liner is electroplated with hard chromium, it is required to have a surface coating of 100 μ m and a surface roughness not exceeding Ra1.6 μ m[2]. Due to the uneven thickness of the spherical surface, it can also lead to uneven coating thickness, affecting the anti-corrosion and wear resistance of the product. In addition, post plating treatment is difficult and the surface roughness is poor. On the other hand, electroplating causes significant environmental pollution, with a large amount of exhaust gas, dust particles, wastewater, and heavy metals, posing a great threat to plants and humans.

If the convex spherical surface of the crown liner is covered with stainless steel plate, it is required that the stainless steel plate is closely attached to the base steel liner plate and there should be no hollowing out. Firstly, the stainless steel plate needs to be pressed into a spherical shape, and then welded onto the base steel lining plate. The process is complicated, and there is no testing method to ensure that the stainless steel plate is tightly attached to the spherical crown. If not tightly attached, after the support is installed under the beam, the spherical stainless steel plate and steel lining plate will detach under the action of the upper load, affecting the normal rotation of the support and posing serious safety hazards. For large tonnage bearings, stainless steel plates can only be customized or spliced, resulting in complex processes and high manufacturing costs.

Therefore, using stainless steel or other corrosion-resistant materials to make football crowns is a method to solve the above problems. However, due to the high price and poor processing performance of stainless steel materials, it is difficult to meet the machining requirements of football crowns, so it is not included in the research object. This article proposes a more optimal method for manufacturing ball crowns using aluminum based alloy materials by referencing European standards. Therefore, according to the standard requirements of bridge spherical bearings, a suitable aluminum alloy material is selected, which requires moderate mechanical properties and is combined with wear-resistant plates to form a friction pair. The linear wear rate, friction coefficient, and anti-corrosion performance of this friction pair are smaller than those of ordinary friction pairs, and the friction surface is smoother. There is no disadvantage of easy corrosion at the edges of chrome plated spherical crown welds, large tonnage welded stainless steel plates, and the manufacturing process is also simpler, Anodizing on the surface can prevent corrosion.

3.2 Selection of Aluminum Alloy Materials

Aluminum alloy is the most widely used non-ferrous metal structural material in industry, and has been widely used in aviation, aerospace, automotive, mechanical manufacturing, shipbuilding, and chemical industries[7]. Referring to the friction pair in European standard EN1337, combined with the mechanical properties and manufacturing process requirements of spherical bearings, select a suitable aluminum alloy material. As the research object, the mechanical performance requirements of forged aluminum alloy with grade 6A02 are shown in Table 1[8].

Table 1 Mechanical property parameters of aluminum alloy materials.

Yield strength (MPa)	Tensile strength (MPa)	Hardness (HB)	Elongation %
>90	>250	⩾70	⩾8

The aluminum alloy material has good mechanical processing performance, and the surface can be mirror polished. It forms a friction pair with a spherical wear-resistant plate, and its performance requirements are shown in Table 2.

Table 2 Technical parameters of aluminum alloy ball crown.

Roughness (Ra)	Friction coefficient	Corrosion resistance performance
⩽0.8μm	⩽0. 03	⩾Chromium plating and welded stainless steel

The developed aluminum alloy specimens meet the chemical composition and mechanical properties of GB/T3190-2008 and GB/T3191-2019 standards. The material has moderate strength and hardness, good plasticity, large bearing capacity, and light weight[9].

4. Experimental Study on Aluminum Alloy Specimens

4.1 Mechanical Performance Testing of Aluminum Alloy

According to the standards of tensile and impact tests, the production of aluminum alloy test bars is carried out, as shown in Figure 2. And conduct tensile and impact tests on tensile and impact testing machines in accordance with GB/T228 and GB/T229; Test the hardness of aluminum alloy materials according to GB/T231.1.

Figure 2 Aluminum alloy test bar sample.

Test environment conditions: The temperature should be controlled at 23±2℃ and the humidity should be maintained at 50% -65%.

The experimental results are shown in Table 3.

Table 3 Mechanical property test of aluminum alloy materials.

Testing items	Tensile test				Impact test	hardness test
	Rp0.2 N/mm^2	Rm N/mm^2	A %	Z %	KV2 J 20℃	(HBW5/250)
Actual measured value	314	371	155.5	28	13	76.3
	298	363	14.5	33	8	76.3
	313	370	15.0	32	14	76.3

According to the experimental results, it can be seen that the strength, hardness, and impact performance of this aluminum alloy meet the requirements of the selection design and relevant standards.

4.2 Wear Test

According to the TB/T 3320 standard for bridge bearings, in order to ensure the service life of bridge bearings, it is necessary to conduct wear tests on the friction pairs of the bearings. Therefore, according to the standard requirements, short distance wear and long distance wear tests were conducted on the friction pair composed of aluminum alloy plates and skateboards.

The short distance wear test adopts modified ultra-high molecular weight polyethylene skateboard according to the bridge support standard, with a specification of Ø100×7mm and a grease storage pit as the wear-resistant plate, and forms a friction pair with mirror aluminum alloy plate for testing. The silicone grease adopts P5201 model.

The test conditions are as follows:

Test temperature: 21±1℃

Positive pressure of the specimen: 45MPa (pressure of 353.43kN)

Relative slip displacement: ±10mm

Relative slip velocity: 15mm/s (sine wave)

Pre compression time: 1 hour

Test standard: Appendix A of TB/T3320-2013 Railway Bridge Spherical Bearings

The experimental results are shown in Table 4.

Table 4 Short distance wear test results of aluminum alloy materials.

Experimental project η	Technical requirements	unit	test result 1#	test result 2#
Line wear rate	≤5	um/km	1.10	1.10
Explain	Accumulated sliding distance: 2km			

After completing the short distance wear test, the surface of the mirror panel is smooth, and the wear of the wear-resistant plate is relatively small, about 1.5um/km, which meets the standard TB/T3320-2013 for railway bridge spherical bearings.

The long-distance wear test was conducted under the same test conditions and standards as the short-distance wear test, and a 15km long-distance wear test was conducted. The test results are shown in Table 5.

Table 5 Results of long distance wear test for aluminum alloy materials.

Experimental project η	Technical requirements	unit	test result 1#	test result 2#
Line wear rate	≤5	um/km	0.55	1.24
Explain	Accumulated sliding distance: 15km			

The experimental photos are shown in Figure 3.

Figure 3 Aluminum alloy mirror panel after experiment.

From the test results, it can be seen that when used in combination with aluminum alloy, the long-distance offline wear is relatively small, less than 5um/km. After the test, the surface of the aluminum alloy is flat and the roughness meets the requirements.

4.3 Neutral Salt Spray Corrosion Test

The salt spray test can be divided into non alumina alloy salt spray test and oxygen aluminum alloy salt spray test according to the surface treatment method of aluminum alloy, in order to verify the anti-corrosion performance of aluminum alloy. The first group of tests uses non alumina alloy plate, small aluminum alloy ball crown and welded stainless steel plate, chrome plated thin plate for comparative testing to verify the anti-corrosion performance of non alumina alloy, The second group of experiments used aluminum alloy samples with anodized surfaces for comparison with welded stainless steel sheets and chrome plated sheets.

The non alumina alloy salt spray test specimen consists of aluminum alloy thin plate, aluminum alloy ball crown, welded stainless steel thin plate, and chrome plated thin plate.

Test conditions: Neutral Salt Spray test(NSS);

Spray mode: continuous spray;

Temperature: 35℃;

Solution: 5% NaCl solution (adjust the pH value of NaOH solution to 7.0);

Salt spray settling capacity: 1.5mL/h;

Test basis: GB/T 10125-2012 Artificial Atmosphere Corrosion Test Salt Spray Test;

Test instrument: Q-FOG cyclic corrosion test chamber.

The experimental results are shown in Table 6.

Table 6 Salt spray test results of non alumina alloy.

Sample Name	Test time	Test result
Aluminum alloy sheet	168h	No corrosion occurs on the surface
Aluminum alloy ball crown	168h	Surface darkening with no obvious white corrosion products
Welding stainless steel sheets surface of stainless steel	168h	There are no rust spots on the surface of stainless steel, and the edge steel substrate produces red rust. The corrosion products flow to the
Chromium plated thin plate	168h	There is no corrosion on the surface of the chrome plated plate, and red rust appears at the edges

The photos taken after the experiment are shown in Figures 4-7.

Figure 4 Aluminum alloy thin plate.

Figure 5 Aluminum alloy ball crown.

Figure 6 Welding of stainless steel sheets.

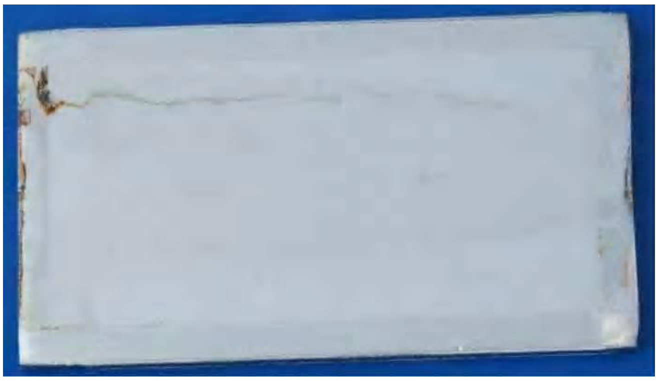

Figure 7 Chromium plated thin plate.

According to the experimental results, aluminum alloy has a slow corrosion rate and strong corrosion resistance; The edges of ordinary chrome plated ball crowns are prone to corrosion, while the welds of stainless steel ball crowns are prone to corrosion. Therefore, the corrosion resistance of aluminum alloy ball crowns is stronger than that of ordinary chrome plated ball crowns and stainless steel ball crowns. When used in dry, low salinity seismic areas, the surface of the spherical crown does not require anodizing treatment.

The aluminum oxide alloy salt spray test specimen consists of aluminum alloy spherical crown with surface anodization, welded stainless steel sheet, and chrome plated sheet.

Test conditions: Neutral Salt Spray test (NSS);

Spray mode: continuous spray;

Temperature: 35±2℃;

Solution: 5% NaCl solution (adjust the pH value of NaOH solution to 6.5-7.2);

Spray volume: 1.5± 0.5ml/80cm^2/h;

Test basis: GB/T 10125-2012 Artificial Atmosphere Corrosion Test Salt Spray Test;

Test instrument: Q-FOG cyclic corrosion test chamber.

The test results are shown in Table 7.

Table 7 Comparison table of aluminum oxide alloy salt spray test.

Sample Name	Test time	Test result
Aluminum alloy spherical crown with surface anodizing	168h	No corrosion occurs on the surface
	480h	No corrosion occurs on the surface
Welding stainless steel sheets	168h	Severe rusting of screw holes and edges in welded stainless steel sheets
	480h	Severe rusting of screw holes and edges in welded stainless steel sheets
Chromium plated thin plate	168h	Chromium plated thin plate paint seam exposed rust
	480h	Rust on paint seams of chrome plated thin sheets

From the experimental results, it can be seen that after anodizing treatment on the surface of the aluminum alloy ball crown, there is no white rust in the salt spray test and the corrosion resistance is stronger; Ordinary chrome plated ball crown paint seams are prone to corrosion, while stainless steel ball crown edge welds are prone to corrosion. Oxidized aluminum alloy ball crowns have stronger corrosion resistance than non-oxidized aluminum alloy ball crowns. In high salinity areas, aluminum alloy spherical crowns with anodized surfaces have a longer lifespan and are particularly suitable for use in coastal areas.

Through the above experiments, it can be concluded that the developed aluminum alloy material is very suitable for making ball crowns. Its mechanical properties, corrosion resistance, and wear resistance can meet the standard requirements, and it is superior to the process of coating stainless steel with ball crowns and electroplating hard chromium on convex spherical surfaces.

5. Research on the Prototype of Aluminum Composite Ball Crown Ball Support

Based on the above research results, using this material has moderate strength, strong impact resistance, low friction coefficient, and can achieve high corrosion resistance requirements by anodizing the surface. It can be made into spherical crowns and used on supports. Moreover, the processing technology is simple, from casting rod cutting, initial milling at both ends, turning spherical surfaces, guiding rounded corners, to spherical polishing, only five steps are needed. Using alloy ball crowns instead of traditional coated stainless steel or chrome plated ball crowns can also greatly reduce the manufacturing cost of the product.

5.1 Trial Production of Aluminum Alloy Ball Crown Prototype

According to the TB/T 3320 standard for railway bearings, different models and sizes of ball crowns are designed, made of developed aluminum alloy and processed according to the manufacturing process. The quality of the produced ball crown samples is tested, and the surface roughness is required to be less than 0.8um, the sphericity is required to be less than 0.2, and the Brinell hardness is greater than 70.

Because aluminum alloy materials have strong corrosion resistance, when used in dry and low salinity areas, the surface can meet anti-corrosion requirements without protection.

Anodize the surface of aluminum alloy to form a hard oxide film, which is difficult to corrode during salt spray testing. This layer of aluminum oxide acts as a protective layer, preventing further reaction or corrosion of the aluminum inside[10]. Improving corrosion resistance, enhancing wear resistance and hardness without affecting roughness, suitable for coastal areas.

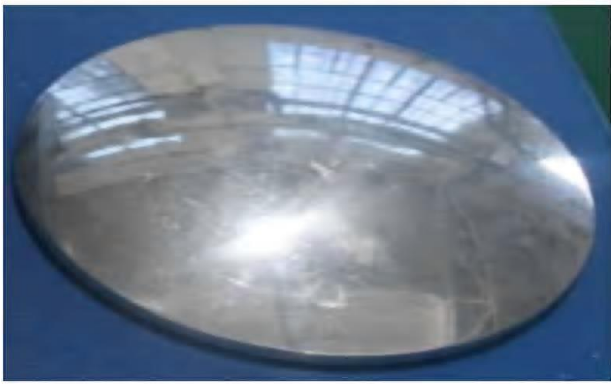

Figure 8 Unprocessed aluminum alloy ball crown physical object. **Figure 9** Physical aluminum alloy spherical crown after anodizing.

5.2 Prototype Testing

The prototype model and quantity manufactured according to relevant standards and design specifications are 2 2000kN fixed spherical supports and 2 2000kN longitudinal spherical supports. The spherical crown is made of aluminum alloy material, with 4 non-oxidized and 2 oxidized. The spherical radius is 360mm, the fixed support height is 125mm, and the longitudinal support is 125mm.

The mechanical performance test items of non-alumina alloy bearings include vertical bearing capacity test, rotational torque test, and friction coefficient test. The test temperature is 21℃, and the test equipment is TYE-10000 compression shear test machine (ZL028). The test standard is carried out according to TB/T3320-2013 Railway Bridge Spherical Bearings. The test results of the specimens are shown in Table 8.

Table 8 Test results of aluminum alloy crown ball bearings.

Support type	Experimental project	Unit	Experimental results	Result determination
000kN fixed spherical support	Vertical deformation	/	0.55	/
	Vertical deformation/total height of support	%	0.44	Qualified
	Rotational torque	N · m	7592.63	Qualified
2000kN longitudinal spherical support	Vertical deformation	/	0.45	/
	Vertical deformation/total height of support	%	0.36	Qualified
	friction coefficient	/	0.012	Qualified

Note: Under the vertical design bearing capacity, for spherical bearings with a total height not exceeding 200mm, the vertical compression deformation should not exceed 2mm; For spherical bearings with a total height greater than 200mm, the vertical compression deformation should not exceed 1% of the support height and should not exceed 4mm; The friction coefficient of the support shall not exceed 0.03; The designed rotational torque of the support is 21600N•m[11]. The experimental photos are shown in Figure 10.

From the finished product tests of 2000kN fixed ball bearings and 2000kN longitudinal ball bearings, it was found that the vertical bearing capacity, rotational performance, and friction coefficient of both bearings meet the requirements of TB/T3320-2013 Railway Bridge Ball Bearings. After the test, the alloy ball crown spherical surface is smooth, without scratches and wear, and the smoothness is very good. The bearing capacity, friction coefficient, hardness, etc. of the alloy crown support meet the support standards and can be used normally. In dry, low salinity seismic areas, the surface of the spherical crown does not require anodizing treatment.

Figure 10 Test photo of aluminum alloy crown ball support.

(Alloy crown ball type support GZZ2016-00149 TJQZ2.0GD-1# **)**

Conduct rotational performance tests on alumina alloy bearings, and the test sample parameters are shown in Table 9.

Table 9 Parameters of aluminum alloy crown ball bearings.

Support type	Vertical load (kN)	Spherical radius (mm)	Support height (mm)	
2000kN alloy crown fixed spherical support	2000	360	127	Aluminum alloy ball crown (surface oxidation)

Test temperature: 26℃

Test equipment: TYE-10000 compression shear testing machine (ZL028)

Test standard: Railway Bridge Spherical Bearings TB/T3320-2013

Test content: Rotation performance test.

The experimental results are shown in Table 10.

Table 10 Performance test results for grasping of aluminum alloy crown ball bearings.

Support type	Experimental project	Standard requirements	Experimental results	Result determination
TJQZ-2000GD-0.1g	Rotational performance	≤21600Nm	12916.5Nm	Qualified

After oxidation treatment, the surface roughness of the aluminum alloy spherical crown remains almost unchanged, and the rotational torque of the support meets the TB/T3320-2013 standard for railway bridge spherical bearings. After the test, the spherical surface is smooth, without scratches, wear, or deformation.

After surface anodizing treatment, the corrosion resistance is stronger, especially suitable for use in coastal areas.

6. Conclusion

(1) The developed aluminum alloy ball crown has obtained a national invention patent. The technology of aluminum alloy ball crown bridge spherical steel support passed the achievement appraisal organized by the Hubei Provincial Department of Science and Technology in 2016, and its achievements reached the international advanced level.

(2) Aluminum alloy materials have high strength, moderate hardness, and good impact resistance. They are combined with wear-resistant plates to form friction pairs, resulting in less linear wear, friction coefficient, and corrosion resistance compared to ordinary friction pairs. The friction surface is smoother, and there are no drawbacks such as easy corrosion at the edges of chrome plated spherical crown welds and large tonnage welded stainless steel plates. Compared to chrome plated ball crowns, the friction surface is more uniform and smooth, and it is not easy to peel off and corrode. It is lighter in weight and less environmentally polluting, making it suitable for use as a friction pair component in bridge bearings.

(3) Aluminum alloy ball crowns are treated with surface anodizing for corrosion resistance, resulting in strong corrosion resistance. The support using aluminum alloy ball crown meets all domestic standard requirements in terms of performance. The use of bridge bearings is a new trend in market development, which is more environmentally friendly, lightweight, has a longer lifespan, and lower maintenance costs.

(4) As the core component of bridge bearings, friction pairs play a crucial role in the performance and service life of bearings. This article conducts research and experiments on one of the friction pair components, the ball crown, and selects a new type of alloy material, which greatly improves the overall performance and service life of bridge bearings. Wear resistant plates are also a key component of friction pairs, and further exploration is needed in future work to continuously improve the performance of bridge bearings.

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