Development of a Long Life and High Corrosion-resistant Bearing for Film Manufacturing Equipment

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Productivity in every industrial field is improving continuously. The productivity of semiconductors or liquid crystal films manufactured in extreme environments, such as vacuums, clean environments, and high temperatures, is also growing. We explain the material and the lubrication used in corrosive environments. In addition, we introduce the development of the corrosion-resistant bearing used in film manufacturing equipment. We succeeded in developing a bearing using steel with high hardness and high corrosion resistance. The new steel has higher corrosion resistance than the existent steel, enables a significant reduction in bearing wear and gives the bearing a long wear life.

Key Words: *film manufacturing equipment, chemical solution, corrosion resistance, hardness, wear, EXSEV bearing*

1. Introduction

In line with the improvement of productivity in all industrial fields, the machining and reaction times of manufacturing processes are becoming shorter and environmental conditions are becoming more sophisticated (e.g. cleaner, higher temperature). Amidst this, the corrosive environment of chemical solutions and corrosive gas used in fields such as semiconductors and flat panel display manufacturing such as LCD (Liquid Crystal Display) is becoming increasingly more diversified and extreme. It is necessary to improve productivity in such harsh environments and long life bearings are in demand.

JTEKT has commoditized the EXSEV (Extreme Special Environment) bearing series featuring various special environment bearings for those applications in which general lubricant and grease cannot be used. This paper will first discuss types and selection of bearing material and lubricant appropriate for the corrosive environment.

Next, we will introduce the long life and high corrosion resistant bearing developed with the aim of extending wear life for use on film manufacturing equipment which requires high corrosion resistance.

2. Materials used in corrosion resistant bearings

Roller bearings are configured from bearing rings, rolling elements, cage and lubricant. **Table 1** shows the metal, resin and ceramic materials used in corrosion resistant bearing components.

The metals used in the bearing ring of corrosion resistant bearings are martensitic stainless steel and precipitation hardening stainless steel. Martensitic stainless steel provides the bearing ring with sufficient hardness however sometimes lacks the necessary corrosion resistance. Precipitation hardening stainless steel has better corrosion resistance but low hardness. The cages use austenitic stainless steel or resin, and solid lubricant is used for lubrication. Through a combination of the bearing rings and rolling elements, it is possible to respond to various environments.

Table 1 Bearing materials for corrosion resistance

Material / Bearing components	Metal			Resin		Ceramics		
	Martensitic stainless steel SUS440C	Precipitation hardening stainless steel SUS630	Austenitic stainless steel SUS304	Fluorocarbon resin FA	PEEK resin PN	Silicon nitride (standard) Si_3N_4	Corrosion resistant silicon nitride Si_3N_4	Silicon carbide SiC
Bearing rings	○	○	—	—	—	○	○	○
Rolling elements	○	—	—	—	—	○	○	○
Cage	—	—	○	○	○	—	—	—

Table 2 Corrosion resistance of steels and resins

Solution	Concentration	Metal			Concentration	Resin	
		Martensitic stainless steel SUS440C	Precipitation hardening stainless steel SUS630	Austenitic stainless steel SUS304		Fluorocarbon resin FA	PEEK resin PN
Water	–	◎	◎	◎	–	Good	Good
Hydrochloric acid	1%	△	○	○	5%	Good	Good
	10%	×	×	×			
Sulfuric acid	1%	○	◎	◎	5%	Good	Good
	10%	△	○	○			
Nitric acid	20%	○	◎	◎	25%	Good	–
Sodium hydroxide	5%	○	○	○	5%	Good	Good
Seawater	–	○	◎	◎	–	Good	Good

25℃ temperature

Corrosion rate ◎: 0.125mm/year or less ○: 0.125 to 0.5mm/year or less
△: 0.5 to 1.25mm/year or less ×: 1.25mm/year or more

2. 1 Metals, resins

Table 2 shows the corrosion resistance of the metals and resins used in EXSEV bearings towards main corrosive chemical solutions[1, 2].

Martensitic stainless steel is the standard material used for the bearing rings and rolling elements of corrosion resistant bearings however precipitation hardening stainless steel is used in environments which require higher corrosion resistance. Furthermore, ceramics are used in highly corrosive acid and alkaline solutions, as well as when there is a need to avoid metal rust mixing with the solution.

Austenitic stainless steel and fluorocarbon resin are the standard materials used for cages. PEEK (Polyetheretherketone) is used for cages which require hardness.

2. 2 Ceramics

Table 3 gives the corrosion resistance of ceramics[1]. The standard ceramic used is silicon nitride. There are two types of corrosion in silicon nitride; the corrosion of sintering additive used to sinter the silicon nitride and the corrosion of silicon nitride itself. If the sintering additive corrodes, corrosion resistant silicon nitride is used, which has improved corrosion resistance due to using different ingredients in the additive. If the silicon nitride itself corrodes, and the sintering additive of the corrosion resistant silicon nitride corrodes, silicon carbide, which has superior corrosion resistance, is used.

There is a strong demand from the market for improvement in the performance of corrosion resistance bearings. Metal material is often used as the cost of ceramics is high, however metal faces the issue of being unable to achieve both wear resistance and corrosion resistance.

Table 3 Corrosion resistance of ceramic materials

Corrosive solutions \ Ceramics	Silicon nitride (standard) Si_3N_4	Corrosion resistant silicon nitride Si_3N_4	Silicon carbide SiC
Hydrochloric acid	C	B	A
Nitric acid	C	B	A
Sulfuric acid	C	B	A
Phosphoric acid	B	B	A
Fluorine acid	C	C	A
Sodium hydroxide	C	C	C
Potassium hydroxide	C	C	C
Sodium carbonate	C	C	C
Sodium nitrate	C	C	C
Water, saltwater	A	A	A

A: Fully resistant B: Almost resistant
C: Slightly susceptible

Note) The corrosive natures of individual solutions differ largely depending on the concentration and temperature. Note that mixing two or more chemicals may increase the corrosivity.

To solve this issue, JTEKT has proceeded with the development of a long life, high corrosion resistant bearing which uses high hardness and corrosion resistant steel. These results are introduced below.

3. Development of the long life and high corrosion resistant bearing

Precipitation hardening stainless steel (hereinafter "corrosion resistant stainless steel") is used in applications where the corrosion resistance of bearing steel and martensitic stainless steel (hereinafter "stainless steel") is insufficient. However, as corrosion resistant stainless steel has lower hardness than stainless steel, when used in bearings, wear of the raceway surface advances rapidly depending on the environment of use and may present a problem insofar as durability of the bearing. As such, this time JTEKT has developed a long life and high corrosion resistant bearing which uses high corrosion resistance and high hardness material for the bearing ring.

3. 1 An example of film manufacturing equipment

The target application of this development was film manufacturing equipment. This is a process in which film is soaked in chemical solution as it is passed through the equipment, as shown in **Fig. 1**. The rolls which carry the film are submerged in the solution and bearings which support the rotating rolls are installed on either side of each roll. The bearings are therefore submerged in the solution, to which the bearing rings and rolling elements are exposed. This chemical solution is made from special ingredients and is corrosive, therefore conventionally, corrosion resistant stainless steel bearings were used. However, due to the raceway surface wear advancing quickly, it was necessary to develop long life bearings in order to improve productivity. The rolling elements of bearings use corrosion resistant silicon nitride with improved corrosion resistance and the cage use PEEK resin which contains solid lubricant.

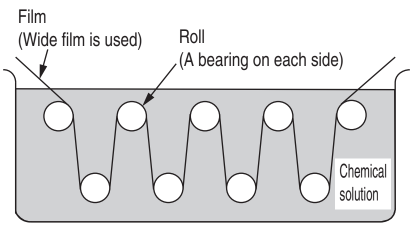


Fig. 1 Schematic illustration of film processing equipment

In recent years, in order to improve the productivity of film, there was a demand for film processing which enabled a wide area of film to be processed in one go and wide film was used. The conveyance rolls became longer and film tension increased, therefore causing the rolls to deflect, as shown in **Fig. 2**. Bearings with good alignment were necessary in order to absorb this deflection. As **Fig. 3** shows, in this example, an aligning ring was attached to the outside of the bearing's outer ring, creating a structure in which the aligning ring and outer ring had a round sliding surface. This structure enables the bearing to follow the tilt of the axis caused by the deflection of the rolls and reduces the bearing moment load.

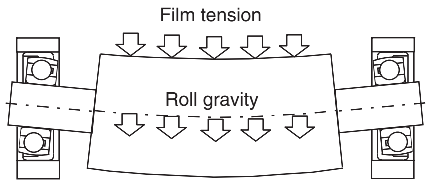


Fig. 2 Deflection of film transfer roll

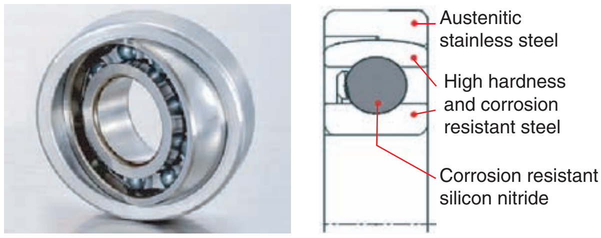


Fig. 3 Appearance and schematic illustration of the bearing with aligning ring

3. 2 Development aims

Grease and oil cannot be used in situations such as that given in the example where the bearing is submerged in chemical solution. Moreover, the solution in which the bearing is submerged lacks sufficient lubrication. As such, the breakage modes of the bearing are not flaking of the raceway surface due to rolling fatigue, but wear of the raceway surface. In the example given, bearings which used corrosion resistant stainless steel in the bearing rings were used however wear of the raceway surface advances fast, making the radial clearance of the bearing excessive, therefore leading to cage breakage or dropping of the balls as a result of cage breakage, and it will no longer be possible to support rotating roll.

When the rolls no longer rotate smoothly, the quality of the film is affected, therefore the bearing is replaced regularly beforehand. However, the manufacturing equipment must stop operation during bearing replacement, therefore from the perspective of improving film productivity, it was necessary to extend the bearing replacement interval.

As mentioned above, grease and oil cannot be used, therefore as a development directive, it was necessary to use a high hardness material on the bearing ring and extend the wear life. However, generally speaking, steel with good corrosion resistance has low hardness and high hardness stainless steel has insufficient corrosion resistance. This time the bearing uses high hardness and corrosion resistance steel which achieves both corrosion resistance and high hardness.

Figure 4 shows the relationship between corrosion resistance and hardness for each material. SUS440C (martensitic stainless steel) has high hardness (60 HRC) but lacks high corrosion resistance. On the other hand, SUS630 (precipitation hardening stainless steel) has extremely high corrosion resistance but low hardness (40 HRC) therefore in the case of the example used this time, wear will progress quickly. This figure demonstrates that high hardness and corrosion resistant steel has a hardness equivalent to SUS440C and a corrosion resistance higher than SUS630.

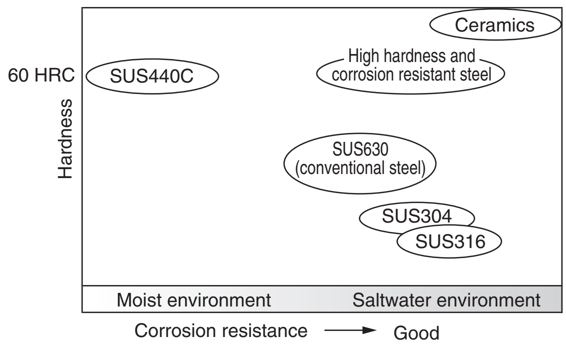


Fig. 4 Corrosion resistance and hardness of materials

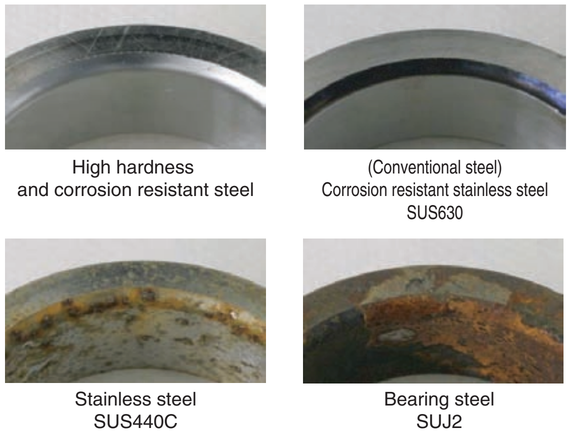
3. 3 Basic evaluation

The performance demands of high hardness and corrosion resistant steel focus on corrosion resistance and rolling wear life, therefore we performed a corrosion test and thrust rolling life test as a basic evaluation.

3. 3. 1 Corrosion test

As a corrosion test, we performed a CASS test which adheres to the salt spray testing of JIS Z2371. In the test we used conventional steel (corrosion resistance stainless steel) and high hardness and corrosion resistant steel, as well as bearing steel (SUJ2) and stainless steel (SUS440C) as references. Moreover, all four of the test specimens used bearing rings of identical size.

Figure 5 shows the results of the CASS test. First, the entire surfaces of the stainless steel and bearing steel for reference are rusted. The conventional corrosion resistant stainless steel had discoloration on its chamfered portion and was beginning to rust, however hardly any rust at all was seen on the high hardness and corrosion resistant steel. This shows that the high hardness and corrosion resistant steel has superior corrosion resistance to the conventional corrosion resistant stainless steel.



Test conditions
Sodium chloride Concentration: 50±5 g/ℓ Temperature: 50±2°C
Copper chloride (II) Concentration: 0.26±0.02 g/ℓ pH: 3.0 to 3.2
Test time: 4 hours

Fig. 5 Results of CASS (Copper-accelerated acid salt spray) test

3. 3. 2 Thrust rolling life test

Next we conducted a thrust rolling life test which is summarized in **Fig. 6**. The test specimens are the flat plate shown in the drawing. The balls used the same corrosion resistant silicon nitride as what is used in the bearing. Moreover, test specimens were submerged in chemical solution to of a concentration and temperature to suit the actual machine and the test environment was made to closely resemble that of film manufacturing equipment. Moreover, the rotational speed during the test was made the same as the orbital speed of the bearing's rolling elements on the film manufacturing equipment, and in regards to test load, the maximum contact stress of the bearing's rolling elements was made the same as the film manufacturing equipment. For the life test, we judged life expiration to be the point where the vibration of the test machine became three times that of the initial state and ended the test here.

As a result of the service life test, we discovered that the high hardness and corrosion resistant steel had a life which was 3.5 times longer than conventional corrosion resistant stainless steel. This means we can anticipate a significant increase in wear life by using high hardness and corrosion resistant steel as bearing material.

When we actually made a bearing using high hardness and corrosion resistant steel in the inner and outer rings and assembled it on film manufacturing equipment to evaluate, its raceway surface had less than 50% of the wear usually witnessed on bearings made from conventional steel.

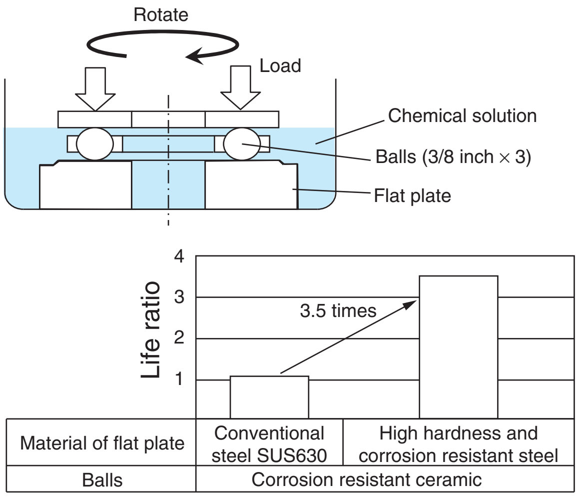


Fig. 6 Thrust rolling service life test equipment

4. Conclusion

This paper introduced the material, lubricant and so on of corrosion resistant bearings, which are one type of EXSEV bearing designed for special environments. Furthermore, by using a bearing made from high hardness and corrosion resistant steel, we were able to extend the life of bearings submerged in the chemical solution of film manufacturing equipment. JTEKT offers a lineup of corrosion resistant bearings, such as ceramic bearings, to suit the environment of use however due to improved productivity and development of new processes in the manufacturing fields of semiconductor and LCD etc., it is predicted that bearings will be required to work in increasingly diverse and extreme environments. As such, JTEKT will continue to engage in bearing development which incorporates new materials and new mechanisms in line with the demands of various special environments of industrial fields, such as corrosive environments.

References

1) JTEKT CORPORATION: CERAMIC BEARINGS AND EXSEV BEARINGS FOR EXTREME SPECIAL ENVIRONMENTS, CAT. No. B2004E-2 (2014).
2) Koyo Engineering Journal No. 145 (1994), 34.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