13. Bearing materials

13.1 Raceway and rolling element

While the contact surfaces of a bearing's raceways and rolling elements are subjected to repeated heavy stress, they must also maintain high precision and rotational accuracy.

To accomplish this, the raceways and rolling elements must be made of a material that has high hardness, is resistant to rolling fatigue, is wear resistant, and has good dimensional stability. The most common cause of fatigue in bearings is the inclusion of non-metallic inclusions in the steel. Nonmetallic inclusions contain hard oxides that can cause fatigue cracks. Clean steel with minimal non-metallic inclusions must therefore be used.

All **NTN** bearings use steel that is low in oxygen content and nonmetallic impurities, refined by a vacuum degassing process and outside hearth smelting. For bearings requiring especially high reliability and long life, steels of even higher in purity, such as vacuum melted steel (VIM / VAR) and electro-slag melted steel (ESR), are used.

13.1.1 Raceway and rolling element materials

1) High/mid carbon alloy steel

In general, steel types capable of being **"through hardened"** below the material surface are employed for raceways and rolling elements. Foremost among these is **high carbon chromium bearing steel**, which is widely used. For large type bearings and bearings with large cross sectional dimensions, induction hardened bearing steel is used, which incorporates manganese(Mn) or molybdenum(Mo). Midcarbon chromium steel incorporating silicon(Si) and manganese may also be used, which gives it hardening properties comparable to high carbon chromium steel.

Table 13.1 (A-140) gives the chemical composition of representative high carbon chrome bearing steels that meet JIS G 4805. SUJ2 is frequently used. SUJ3, with enhanced hardening characteristics containing a large quantity of Mn, is used for large bearings. SUJ5 is SUJ3 to which Mo has been added to further enhance hardening characteristics, and is used for oversized bearings or bearings with thick walls.

Table 13.1 (A-140) lists the chemical composition of the primary materials that are equivalent or similar to these JIS high carbon chrome bearing steels. The chemical composition of JIS SUJ2 is nearly equivalent to that of AISI, SAE standard 52100, German DIN standard 100Cr6, and Chinese GB standard GCr15.

2) Carburizing (case hardened) steel

Carburizing hardens the steel from the surface to the proper depth, leaving a relatively soft core. This provides **hardness and toughness**, making the material **suitable for impact loads**. **NTN** uses carburizing (case hardened) steel for most of its tapered roller bearings. In terms of case hardened steel for **NTN**'s other bearings, chromium steel and chrome molybdenum steel are used for small to medium sized bearings, and nickel chrome molybdenum steel is used for large sized bearings. **Table 13.2** (A-141) shows the chemical composition of representative carburizing steels of JIS.

The table lists the chemical composition of similar materials. The chemical composition of JIS SCM420 is nearly equivalent to that of AISI, SAE standard 4118, German DIN standard 20CrMo4 or 25CrMo4. Chinese GB standard has a slightly different amount of Cr and Mo compared with G20CrMo.

3) High temperature capable bearing steel

When bearings made of ordinary high carbon chromium steel which have undergone standard heat treatment are used for long durations at high temperatures, unacceptably large dimensional changes can occur as described in section 13.1.2. For this reason, **a dimension stabilizing treatment** (TS treatment) has been devised for very high temperature applications. This treatment however reduces the hardness of the material, thereby reducing rolling fatigue life. (See section "3.3.2 Bearing characteristics factor a_2" on page A-22.) Note that dimensional changes can occur in normal use too.

Standard high temperature bearings for use at temperatures from **150°C - 200°C**, add silicon to the steel to improve heat resistance. This results in a bearing with excellent rolling fatigue life with minimal dimensional change or softening at high temperatures.

A variety of heat resistant steels are also incorporated in bearings to minimize softening and dimensional changes when used at high temperatures. Two of these are high-speed molybdenum steel and high-speed tungsten steel. For bearings requiring heat resistance in high speed applications, there is also heat resistant case hardened molybdenum steel (see **Table 13.3** on A-142).

4) Corrosion resistant bearing steel

For applications requiring high corrosion resistance, **stainless steel** is used. To achieve this corrosion resistance, a large proportion of the alloying element chrome is added to martensitic stainless steel (**Table 13.4** on A-142).

5) Induction hardened steel

Besides the use of surface hardening steel, induction hardening is also utilized for bearing raceway surfaces, and for this purpose **mid-carbon steel** is mainly used for its lower carbon content instead of through hardening steel.

Table 13.5 (A-142) shows the chemical composition of the primary materials that are similar to the representative medium carbon steels (machine structural carbon steels) of JIS used for small products. For deep hardened layers required for **larger bearings** and **bearings with large surface dimensions, mid-carbon steel is fortified with chromium and molybdenum**.

6) Other bearing materials

For ultra high speed applications and applications requiring very high level corrosion resistance, ceramic bearing materials such as Si_3N_4 are also available.

13.1.2 Properties and characteristics of bearing Materials

1) Physical and mechanical properties of bearing materials (besides resin)

Table 13.6 and **Table 13.7** (A-143) show physical and mechanical properties of the representative materials used for raceways, rolling elements, and cages.

2) Dimensional change of bearings

Dimensions of bearings used for a long time may change depending on the use condition. This phenomenon is called dimensional change.

<Mechanism of dimensional change>

A standard bearing steel structure contains a small amount of austenite in the matrix of hard martensite. This austenite is partially retained austenite without being transformed into martensite in the cooling process of the bearing steel quenching process, and is called residual austenite.

Since the residual austenite is an unstable structure, it is transformed into a stable structure (martensite) when the bearing is being used. This structure transformation is the cause of the dimensional change of bearings.

Fig. 13.1 shows measured values of dimensional change of a standard bearing held at 120°C over an extended period of time.

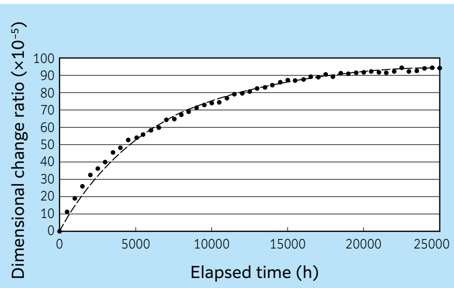


Fig. 13.1 Example of dimensional change rate of standard bearings that are held at 120°C for a long time (measured values)

The dimensional change rate becomes larger as the elapsed time or the temperature of exposure increases.

Depending on the use condition, dimensional change may occur with bearings made of general bearing steel that did not reach 100°C, which is the normal limit.

Bearings that underwent dimension stabilization treatment (TS treatment) have a significantly lower dimensional change. For details, please contact **NTN** Engineering.

<Dimensional change problems and countermeasures>

Among dimensional change, particular attention should be paid to inner ring expansion.
When the inner ring expands by dimensional change, the interference between the inner ring and the shaft decreases, and the bearing may be heavily damaged by creeping or axial movement. Therefore, when a bearing is to be used for a long time, the bearing specifications and fixing method must be determined with the interference decrease due to dimensional change taken into consideration. **For example, the interference can be increased (see section "7. Bearing fits") or fixing in the axial direction can be reinforced (see section "14. Shaft and housing design")**.

<Situations to monitor dimensional change>

The dimensional change of bearings is expressed by the bearing dimension × dimensional change rate. Therefore, under a given temperature and elapsed time, larger bearings show greater dimensional change. Pay particular attention to the amount of dimensional change when large bearings are to be used with fits with small interference.

In addition, dimensional change does not occur during the rotation inspection immediately following bearing installation. It is observed after a long-period operation. Therefore, for machines and parts used for a long time, periodic inspection

is effective for preventing problems. For detailed consideration, please consult **NTN** beforehand.

13.2 Cage

Bearing cage materials must have the strength to withstand rotational vibrations and shock loads. These materials must also have a low friction coefficient, be lightweight, and be able to withstand bearing operating temperatures.

13.2.1 Metal materials

For **small** and **medium sized bearings**, pressed steel cages of **cold** or **hot rolled material** with a low carbon content of approx. 0.1% are used. However, depending on the application, **austenitic stainless steel** is also used. Machined cages are generally used for **large bearings**. **Carbon steel for machine structures** or **high-strength cast brass** is frequently used for the cages, but other materials such as **aluminum alloy** are also used. **Table 13.8** and **Table 13.9** (A-143) show the chemical composition of the representative cage materials.

Besides **high-strength brass**, medium carbon **nickel**, **chrome** and **molybdenum steel** that has been hardened and tempered at high temperatures are also used for bearings used in aircraft. The materials are often **plated with silver** to enhance lubrication characteristics.

13.2.2 Resin materials

Recently resin cages are used in place of metals because the material is lightweight and easy to mold into complicated shapes. On the other hand, resins have disadvantages such as lower strength and heat resistance. Therefore, it is important to select resin materials that take advantage of their characteristics. **Table 13.10** (A-144) shows the characteristics of the representative cage resin materials. These materials are rarely used without being filled, and are usually reinforced with glass fiber (GF) or carbon fiber (CF).

[Characteristics of resin materials]

(Advantages)

- Lightweight
- High corrosion resistance
- High self-lubricating performance with less abrasion powder
- Low noise
- Can easily be molded into complicated shapes and various designs
- High productivity

(Disadvantages)

- Lower strength compared with metal
- Lower heat resistance compared with metal
- The strength and elastic modulus largely vary widely with temperature.
- The physical properties (strength) may change when resins are exposed to high temperatures for a long period.
- The strength may deteriorate when resins are exposed to certain types of chemical or oils.
- The thermal expansion coefficient is high, and the dimensional change is larger compared with metal.

<<Polyamide (PA): 66, 46>>

Polyamide is suitable for general cage materials because it is low cost and has high strength, heat resistance, wear resistance, and formability. This material has disadvantages such as high water absorbency, physical property deterioration and dimensional change due to water absorption. On the other hand, water absorption increases flexibility and toughness, enhancing the ease of assembly and shock resistance of cages. However, the physical property (strength) may deteriorate rapidly at high temperatures when polyamide is exposed to lubricating oil containing an S (suflur) type or P (phosphorus) type extreme pressure additive.

Polyamide 66 reinforced with glass fibers is the most used material because it has excellent performance as a cage material.

<<Polyphenylene sulfide (PPS)>>

Polyphenylene sulfide has high heat resistance (continuous operating temperature: 220 to 240°C), chemical resistance, melt fluidity, and formability.

<<Polyetheretherketone (PEEK)>>

Polyetheretherketone has the highest heat resistance among thermoplastic resins (continuous operating temperature: 240 to 260°C). It has excellent self-lubricating performance, shock resistance, and chemical resistance, but it is very expensive. It is mainly used for cages of high-speed bearings for machine tools.

<<Fabric reinforced phenolic resin>>
Phenolic resin is a thermosetting resin. It overcomes the disadvantages of hard and brittle phenolic resin having low shock resistance using fabric reinforcement. It is lightweight and has high lubricity and good mechanical properties. Injection molding cannot be performed because of the thermosetting property, so cages are made by machining. It is mainly used for cages of high-speed angular contact ball bearings for machine tools.

13.3 Rubber seal materials

Synthetic rubbers with high heat resistance and oil resistance are used as materials for seals. Different rubber is used depending on the degree of heat resistance.

Table 13.11 (A-144) shows the representative characteristics of the rubber materials.

<<Nitrile rubber (NBR)>>
Nitrile rubber has high oil resistance, heat resistance, and wear resistance, and is widely used as a general material for seals. The operating temperature range is -20 to 120°C.

<<Acrylic rubber (ACM)>>
Acrylic rubber has high heat resistance and can be used above the application temperature of NBR. It has excellent oil resistance but swells in ester oil. An ester oil resistant grade is also available. The operating temperature range is -15 to 150°C.

<<Fluorinated rubber (FKM)>>
Fluorinated rubber is a rubber material having excellent heat resistance, oil resistance, and chemical resistance. It is deteriorated by amine, so attention needs to be paid when combining fluorinated rubber with urea grease that precipitates amine at high temperatures. The operating temperature range is -30 to 230°C.

13.4 Periphery of bearing (shaft, housing)

Table 13.12 (A-145) and **Table 13.13** (A-145) show physical and mechanical properties of representative materials used for shafts and housings. Heat treatment is applied to bearing materials that are used under large loads. Steel with enhanced bending strength and wear resistance (fretting strength) is used. For such applications, bearing materials (**Table 13.6** and **Table 13.7** on A-143) may also be used as shaft materials.

For housing materials that are used under large loads, heat treatment is applied, and materials with enhanced wear resistance (fretting strength) are used. For lightweight applications, aluminum alloy is widely used.

13.5 NTN bearings with prolonged life

NTN is promoting approaches and research and development from various perspectives with respect to long operating life of bearings. Two examples of approaches for bearing materials and heat treatment, (1) TAB/ETA/EA bearings and (2) FA tapered roller bearings will be introduced in the following sections.

13.5.1 TAB/ETA/EA bearing series

1) Characteristics

(1) Effective for lubrication conditions with foreign matter having high hardness
The main cause of the damage of transmission bearings of automobiles is foreign matter in the lubricating oil. TAB/ETA/EA bearings can be used to prolong the operating life of machines under such contaminated lubricating oil conditions.

(2) High peeling strength
Peeling damage is often caused by deterioration of lubrication conditions during use. The limit life can be prolonged by enhancing the bearing's peeling resistance.

2) Mechanism of prolonged bearing life
Bearing damage is often seen on the raceway surface. By applying heat treatment and selecting appropriate materials, the surface structure has enhanced toughness and improved resilience without impairing the surface hardness. In addition, for tapered roller bearings, crowning is also optimized. These suppress suppresses the occurrence of small cracks that might become the starting point of peeling and damage, prolonging the operating life.

(1) Crack resistance and stress releasing effect
The residual austenite, which is softer than the martensitic parent phase, has an effect of relieving stress concentrations acting on the periphery of the dent formed by foreign matter on the rolling contact surface under lubrication conditions with foreign matter mixed into the oil, thereby suppressing the occurrence of cracks.

As shown in **Fig. 13.2**, all the residual stress on the top surface of the dent part is shifted to the tensile side. The standard heat-treated product of through hardened steel has residual tensile stress. When a specially heat-treated product and a standard heat-treated product are compared, the special heat treated material has less shifting of stresses to the tensile side, which can be harmful, and a stress release action is observed.

(2) Reason for long operating life
ETA and EA bearings have a structure with an appropriate amount of residual austenite and carbide dispersed on the surface region, and the structure is thermally stabilized by the special heat-treatment mentioned above.

The qualities of the material (residual stress, hardness, micro-structure) of a raceway surface generally change due to heat generation and shearing stress action during rolling contact, leading to fatigue cracks. Therefore, improving resistance to temper softening is effective to prevent surface-initiated damage. The residual austenite obtained by ordinary carburizing can suppress generation and progress of cracks and is work-hardened during use (the strength increases). Therefore, by using an appropriate amount of it, the material becomes tough. However, it is unstable against heat. On the other hand, when nitrogen is introduced and diffused under an appropriate condition, a matrix of residual austenite and matensite parent phase that is stable against heat is formed, and the material becomes resilient against quality changes.

3) Supported bearing sizes

Table 13.15

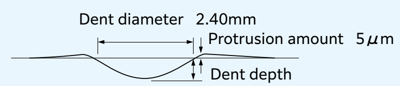
●Deep groove ball series	●Tapered roller series
TAB000 to TAB020	All types that have bearing diameter to be equal to or lower than ϕ600
TAB200 to TAB217	
TAB300 to TAB311	

For other types besides the above, please contact **NTN** Engineering.

Table 13.14 Comparison of dent shapes of each material

Material		Surface hardness [HRC]	Residual austenite amount [%]	Dent diameter [mm]	Dent depth [μm]	Protrusion amount [μm]
Through hardened steel	Standard bearing	62.0	10	2.40	80	5
	TAB bearing	62.0	28	2.45	83	4
Carburizing steel	Standard bearing	61.0	25	2.80	102.5	1
	ETA bearing	62.5	29	2.63	97.5	1

Example of dent shape



(Example of through hardened steel bearing)

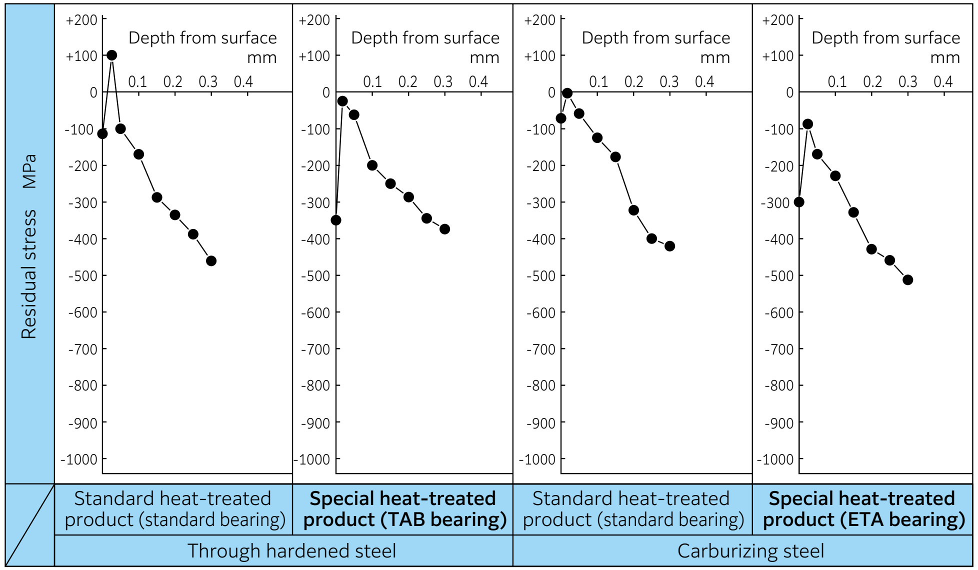


Fig. 13.2 Residual stress within a dent

4) Operating life test

The life test results of a standard bearing, a TAB bearing, and an ETA bearing are shown, but the data is for reference because it varies depending on the type of foreign matter under the contaminated lubricant condition.

(1) Tested bearings and test conditions

Table 13.16 shows tested bearings, and **Table 13.17** and **Table 13.18** shows the test conditions.

(2) Operating life data

Condition of lubricating oil containing foreign matter (reference)

Fig. 13.3 and **Fig. 13.4** show the results of tests conducted under lubrication conditions mixed with **NTN** standard foreign matter.

Table 13.16 Tested bearings

Bearing name	Boundary dimensions (mm)
Standard 6206	$\phi 30 \times \phi 62 \times 16$
TAB bearing TAB206	↑
Standard 30206	$\phi 30 \times \phi 62 \times 17.25$
ETA bearing ETA-30206	↑

Table 13.17 Test condition (6206, TAB206)

Radial load (kN)	6.9
Rotational speed (mm^{-1})	2 000
Lubricating oil	Turbine 56 + **NTN** standard foreign matter
Lubrication method	Oil bath

Table 13.18 Test condition (30206, ETA-30206)

Radial load (kN)	17.64
Rotational speed (mm^{-1})	2 000
Lubricating oil	Turbine 56 + **NTN** standard foreign matter
Lubrication method	Oil bath

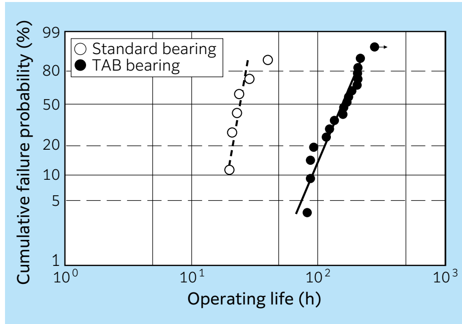


Fig. 13.3 Operating life comparison between TAB deep groove bearing and standard bearing (mixed with foreign matter)

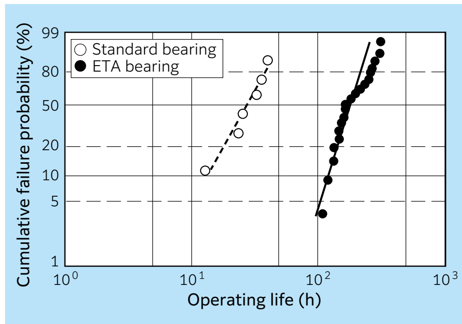


Fig. 13.4 Operating life comparison between ETA tapered roller bearing and standard bearing (mixed with foreign matter)

13.5.2 FA tapered roller bearings

NTN developed special heat treatment (FA treatment) for refining crystal grains of bearing steel to half or less the size of the conventional ones by focusing on refining strengthening of crystal grains. (See **Fig. 13.5**) **NTN** adopted this technique for "FA tapered roller bearings," thereby improving the indentation resistance and realizing long operating life under the lubrication conditions including foreign matter. Further, by combining optimization techniques for the internal bearing design acquired during development of the ECO-Top series, the seizure resistance is improved and the bearing size can be greatly reduced.

Remarks: FA is an abbreviation of fine austenite strengthening treatment.

FA treatment (Fine Austenite Strengthening)

- Longer operating life is realized by crystal grain refinement of bearing steel.
- The crystal grains of bearing steel are refined to half or less the size of the conventional ones.

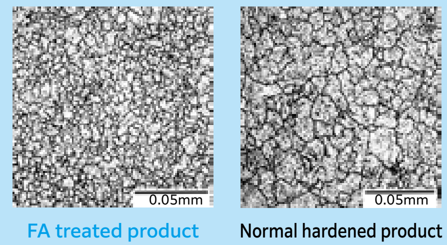


Fig. 13.5 Former austenite crystal grain boundary

1) Longer operating life

- Rolling fatigue life is improved by crystal grain refinement.
- The residual austenite amount is optimized by carbonitriding, and resistance to surface-initiated damage caused by rolling over foreign matter is improved by the crystal grain refinement technique.

- Special crowning that is designed to obtain optimum surface pressure distribution under light to heavy load conditions is adopted.

Thus, the operating life under the lubrication condition including oil types and foreign matter close to the actual machine was greatly extended compared with the standard product.

2) Optimum oil film formation design

The rib area of a tapered roller bearing has sliding contact, and the quality of the oil film forming capability of this area greatly affects the bearing performance.

In the FA tapered roller bearing, the oil film forming capability of the rib area is improved by optimization techniques involving parameters such as the shape, accuracy, and roughness of the contact area of the flange and the roller acquired during ECO-Top bearing development. Thus, the rotational torque is reduced, and the seizure resistance and the preload loss resistance are improved.

3) Seating of assembly width

When a tapered roller bearing is to be used under preload, it is necessary to give sufficient stable rotation to the bearing and bring the bearing into a proper state in which the roller end surface and the inner ring rib surface are brought into contact with each other.

The smaller the number of stable rotations, the more reliably the preload setting can be achieved, and the assembly work becomes more efficient.

With FA tapered roller bearings, preload can reliably be set in a short time by the optimization of the internal bearing design. For example, it may become possible to stop applying gear oil to help achieve early stabilization. The roller becomes stable at a rotation speed equal to that of a conventional bearing by using only rust preventative oil.

4) Improvement in indentation resistance

To make bearings smaller, it is necessary to improve the indentation resistance to prevent safety factor decrease caused by a decrease of the static load rating.

Regarding FA tapered roller bearings, the indentation depth is less than one ten-thousandth of the rolling element diameter even under the static load with a safety factor (S_0) = 0.6.

5) Test data

(1) Operating life

(Condition of linear contact type operating life test)

Test machine	: **NTN** linear contact life test machine
Test piece	: ϕ12 × L12, R480
The other test piece	: ϕ20 Roller(SUJ2)
Load (kN)	: 13.74
Contact stress (Mpa)	: 4 155 (P_{max})
Lubricating oil	: Turbine oil 68

Table 13.19 Result of operating life test under clean lubricating oil condition (Result of comparison test with linear contact type test piece)

Heat treatment method	L_{10} operating life, × 10[4] cycles	L_{10} life ratio
4Top	1 523	1.0
ECO-Top(ETA)	3 140	2.1
FA	4 290	2.8

*L_{10} life ratio is the comparison when 4Top is 1.0.

(Condition of bearing operating life test)

Test machine	: **NTN** life test machine
Tested bearings	: (1)30206
	: (2)30306D
Test load	: (1)F_r = 17.64kN, F_a = 1.47kN
	: (1)F_r = 19.6kN, F_a = 13.72kN
Rotational speed	: 2 000min^{-1}
Lubrication	: (1)Turbine oil 56 oil bath (30 ml)
	: (2)ATF oil bath (50 ml)
Foreign matter	: (1)50µm or below : 90wt%, 100～180µm : 10wt% } 1.0g/l
	: (2)50µm or below : 75wt%, 100～180µm : 25wt% } 0.2g/l
Calculated operating life	: (1)169h (No foreign matter)
	: (2)171h (No foreign matter)

Table 13.20 Result of operating life test under lubrication condition including foreign matter (Result of comparison test by bearings)

Test condition		4Top	ECO-Top(ETA)	FA
Condition (1)	L_{10} operating life (h)	52.4	314.9	415.6
	L_{10} life ratio	1.0	6.0	7.9
Condition (2)	L_{10} operating life (h)	22.5	—	309.7
	L_{10} life ratio	1.0	—	13.8

*L_{10} life ratio is the comparison when 4Top is 1.0.

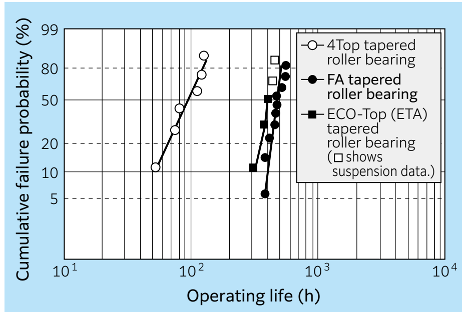


Fig. 13.6 Condition (1) 30206 operating life test result (lubrication condition including foreign matter)

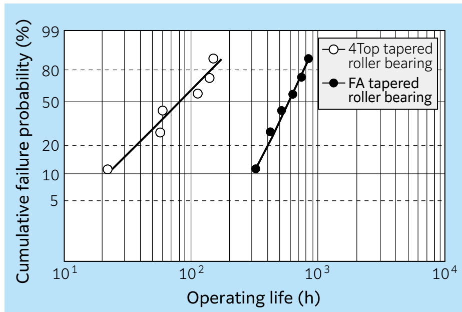


Fig. 13.7 Condition (2) 30306D operating life test result (lubrication condition including foreign matter)

(2) Rotational torque

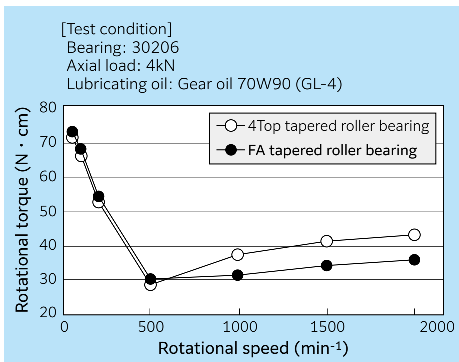


Fig. 13.8 Result of rotational torque measurement

(3) Seizure resistance

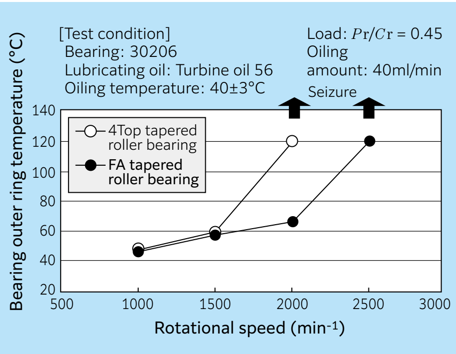


Fig. 13.9 Results of temperature rise test

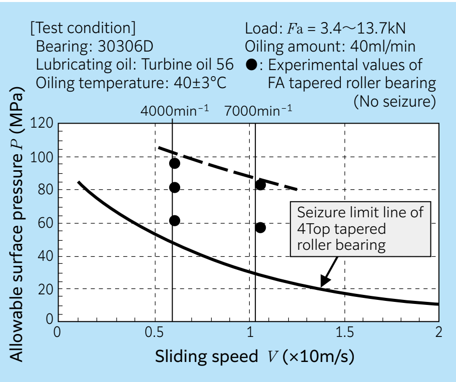


Fig. 13.10 Results of PV limit test

(4) Preload release resistance

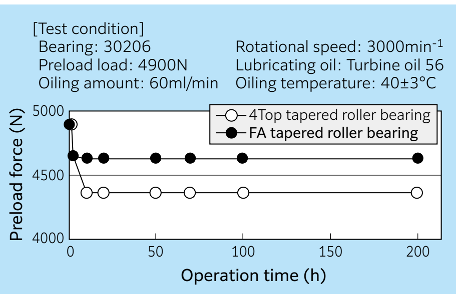


Fig. 13.11 Results of preload release test

(5) Seating of assembly width

Bearing : 30206
Axial load : 29.4N
Test method : A bearing is placed in the configuration shown in the figure, and an axial load (weight) is applied to rotate the inner ring. The drop amount of the inner ring for each rotation is measured to obtain the rotational speed until it is stable.

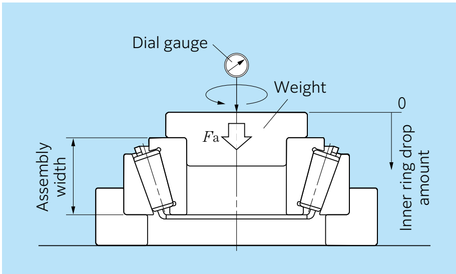


Fig. 13.12 Measurement method of revolutions to seated bearing width

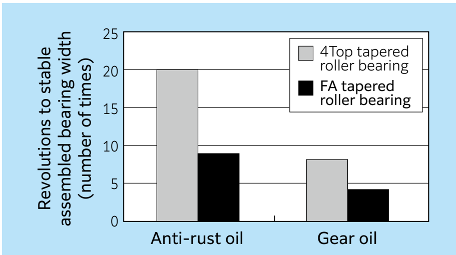


Fig. 13.13 Measurement result of revolutions to seated bearing width

(6) Indentation resistance

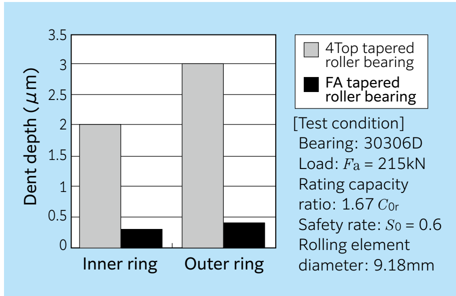


Fig. 13.14 Measurement result of dent depth

6) Downsizing with FA tapered roller bearing

Improvement in the bearing life, seizure resistance, and indentation resistance strength allows the compact ratio below by adopting an FA tapered roller bearing (**Fig. 13.15**).

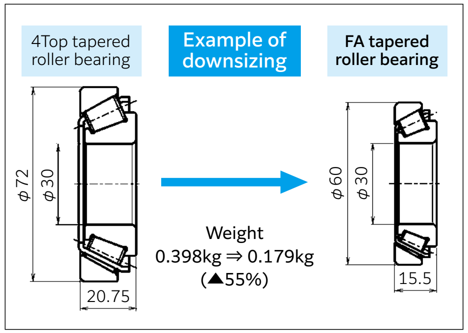


Fig. 13.15 Example of compact ratio

7) Supported bearing size

The target bearings are bearings with an outer diameter of φ145 or below. Contact **NTN** Engineering for details.

13.6 Bearing fatigue analysis technique

In a region subjected to plastic deformation due to rolling fatigue, various X-ray analysis parameters obtained by X-ray stress measurements (residual stress, diffraction half-value with, and residual ausentite) may be observed. There is a technique that estimates the degree of progress of rolling fatigue (degree of fatigue) based on the X-ray stress measurement result using this characteristic (**Fig. 13.16**). Since the mid-1980s, **NTN** has been investigating the relationship between the X-ray analysis value (fatigue degree in **Fig. 13.16**) and the life ratio (a value expressed by the percentage of the operating time in which peeling occurred is 100%) for surface-initiated damage (peeling and early peeling starting from dents), which has been frequently observed in the field. Since the relationship changes depending on various rolling conditions (combination of surface roughness, load, and lubrication condition), the values are used for reference; however, the remaining operating life can be estimated by using this relationship diagram.

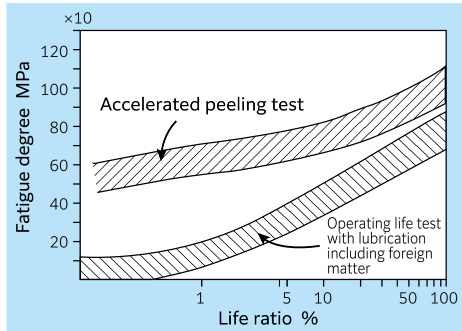


Fig. 13.16 Relationship between degree of fatigue and life ratio

Recently, fatigue degree estimation is being studied using variation in X-ray diffraction ring peak intensity with high sensitivity even in the latter stage of fatigue.

Table 13.1 Chemical composition of representative high carbon chrome bearing steels

Country name	Standard name	Code	Main chemical composition (%)								Equivalent/ approximate steel of JIS
			C	Si	Mn	P	S	Ni	Cr	Mo	
Japan	JIS G 4805 (2008)	SUJ2	0.95∼1.10	0.15∼0.35	≦0.50	≦0.025	≦0.025	≦0.25	1.30∼1.60	≦0.08	
		SUJ3	0.95∼1.10	0.40∼0.70	0.90∼1.15	≦0.025	≦0.025	≦0.25	0.90∼1.20	≦0.08	
		SUJ4	0.95∼1.10	0.15∼0.35	≦0.50	≦0.025	≦0.025	≦0.25	1.30∼1.60	0.10∼0.25	
		SUJ5	0.95∼1.10	0.40∼0.70	0.90∼1.15	≦0.025	≦0.025	≦0.25	0.90∼1.20	0.10∼0.25	
USA	ASTM A1040 (2010)	50100	0.98∼1.10	0.15∼0.35	0.25∼0.45	≦0.025	≦0.025	≦0.25	0.4∼0.6	≦0.10	
		51100	0.98∼1.10	0.15∼0.35	0.25∼0.45	≦0.025	≦0.025	≦0.25	0.90∼1.15	≦0.10	
	ASTM A295/295M (2014) AISI A295/295M (2014) SAE AMS 6440S (2015)	52100	0.93∼1.05	0.15∼0.35	0.25∼0.45	≦0.025	≦0.015	≦0.25	1.35∼1.60	≦0.10	SUJ2
	ASTM A485 (2014)	A485 Grade1	0.90∼1.05	0.45∼0.75	0.90∼1.20	≦0.025	≦0.015	≦0.25	0.90∼1.20	≦0.10	SUJ3
France/ Germany	NF EN ISO 683-17 (2014) · DIN EN ISO 683-17 (2014)	100Cr6	0.93∼1.05	0.15∼0.35	0.25∼0.45	≦0.025	≦0.015	—	1.35∼1.60	≦0.10	SUJ2
		100CrMnSi4-4	0.93∼1.05	0.45∼0.75	0.90∼1.20	≦0.025	≦0.015	—	0.9∼1.20	≦0.10	SUJ3
		100CrMnSi6-4	0.93∼1.05	0.45∼0.75	1.00∼1.20	≦0.025	≦0.015	—	1.40∼1.65	≦0.10	
		100CrMo7	0.93∼1.05	0.15∼0.45	0.25∼0.45	≦0.025	≦0.015	—	1.65∼1.95	0.15∼0.30	
		100CrMo7-3	0.93∼1.05	0.15∼0.45	0.60∼0.80	≦0.025	≦0.015	—	1.65∼1.95	0.20∼0.35	
		100CrMnMoSi8-4-6	0.93∼1.05	0.40∼0.60	0.80∼1.10	≦0.025	≦0.015	—	1.80∼2.05	0.50∼0.60	
Germany	DIN	105Cr4	1.00∼1.10	0.15∼0.35	0.25∼0.40	≦0.030	≦0.025	—	0.90∼1.15	—	
China	GB/T 18254 (2002)	GCr4	0.95∼1.05	0.15∼0.30	0.15∼0.30	≦0.025	≦0.020	≦0.25	0.35∼0.50	≦0.08	
		GCr15	0.95∼1.05	0.15∼0.35	0.25∼0.45	≦0.025	≦0.025	≦0.30	1.40∼1.65	≦0.10	SUJ2
		GCr15SiMn	0.95∼1.05	0.45∼0.75	0.95∼1.25	≦0.025	≦0.025	≦0.30	1.40∼1.65	≦0.10	
		GCr15SiMo	0.95∼1.10	0.65∼0.85	0.20∼0.40	≦0.027	≦0.020	≦0.30	1.40∼1.70	0.30∼0.40	
		GCr18Mo	0.95∼1.05	0.20∼0.40	0.25∼0.40	≦0.025	≦0.020	≦0.25	1.65∼1.95	0.15∼0.25	

Bearing Materials

NTN

Commentary

Table 13.2 Comparison table of main material components of each country (carburizing steel)

Country name	Standard name	Code	Main chemical composition (%)								Equivalent/ approximate steel of JIS
			C	Si	Mn	P	S	Ni	Cr	Mo	
Japan	JIS G 4053 (2016)	SCr420	0.18∼0.23	0.15∼0.35	0.60∼0.90	≦0.030	≦0.030	≦0.25	0.90∼1.20	—	
		SCr435	0.33∼0.38	0.15∼0.35	0.60∼0.90	≦0.030	≦0.030	≦0.25	0.90∼1.20	—	
		SCM420	0.18∼0.23	0.15∼0.35	0.60∼0.90	≦0.030	≦0.030	≦0.25	0.90∼1.20	0.15∼0.25	
		SCM435	0.33∼0.38	0.15∼0.35	0.60∼0.90	≦0.030	≦0.030	≦0.25	0.90∼1.20	0.15∼0.30	
		SNCM420	0.17∼0.23	0.15∼0.35	0.40∼0.70	≦0.030	≦0.030	1.60∼2.00	0.40∼0.60	0.15∼0.30	
		SNCM815	0.12∼0.18	0.15∼0.35	0.30∼0.60	≦0.030	≦0.030	4.00∼4.50	0.70∼1.00	0.15∼0.30	
USA	AISI A29/29M (2015) SAE J404 (2009)	5120	0.17∼0.22	0.15∼0.35	0.70∼0.90	≦0.035	≦0.040	≦0.25	0.70∼0.90	≦0.06	SCr420
		4118	0.18∼0.23	0.15∼0.35	0.70∼0.90	≦0.035	≦0.040	≦0.25	0.40∼0.60	0.08∼0.15	SCM420
		4135	0.33∼0.38	0.15∼0.35	0.70∼0.90	≦0.035	≦0.040	≦0.25	0.80∼1.10	0.15∼0.25	SCM435
		4320	0.17∼0.22	0.15∼0.35	0.45∼0.65	≦0.035	≦0.040	1.65∼2.00	0.40∼0.60	0.20∼0.30	SNCM420
		8620	0.17∼0.22	0.15∼0.35	0.70∼0.90	≦0.035	≦0.040	0.40∼0.60	0.40∼0.60	0.15∼0.25	SNCM220
	AISI A29/29M(2015)	5135	0.33∼0.38	0.15∼0.35	0.60∼0.80	≦0.035	≦0.040	≦0.25	0.80∼1.05	≦0.06	SCr435
	AISI SAE AMS 6263M (2016)	9315	0.11∼0.17	0.15∼0.35	0.40∼0.70	≦0.025	≦0.025	3.00∼3.50	1.00∼1.40	0.08∼0.15	SNCM815
France/ Germany	NF EN ISO 683-17 (2014) · DIN EN ISO 683-17 (2014)	20Cr4	0.17∼0.23	≦0.40	0.60∼0.90	≦0.025	≦0.015	—	0.90∼1.20	—	SCr420
		20CrMo4	0.17∼0.23	≦0.40	0.60∼0.90	≦0.025	≦0.015	—	0.90∼1.20	0.15∼0.25	SCM420
		20NiCrMo7	0.17∼0.23	≦0.40	0.40∼0.70	≦0.025	≦0.015	1.60∼2.00	0.35∼0.65	0.20∼0.30	
		18NiCrMo14-6	0.15∼0.20	≦0.40	0.40∼0.70	≦0.025	≦0.015	3.25∼3.75	1.30∼1.60	0.15∼0.25	
	NF EN 10084(2008) · DIN EN 10084(2008)	17NiCrMo6-4	0.14∼0.20	≦0.40	0.60∼0.90	≦0.025	≦0.035	1.20∼1.50	0.8∼1.10	0.15∼0.25	
	NF EN 10083-1 (1996) · DIN EN 10083-1 (1996)	37Cr4	0.34∼0.41	≦0.40	0.60∼0.90	≦0.035	≦0.035	—	0.90∼1.20	—	SCr435
		25CrMo4	0.22∼0.29	≦0.40	0.60∼0.90	≦0.035	≦0.035	—	0.90∼1.20	0.15∼0.30	SCM420
		34CrMo4	0.30∼0.37	≦0.40	0.60∼0.90	≦0.035	≦0.035	—	0.90∼1.20	0.15∼0.30	SCM435
China	GB/T 3203 (1982)	G20CrMo	0.17∼0.23	0.20∼0.35	0.65∼0.95	≦0.030	≦0.030	—	0.35∼0.65	0.08∼0.15	
		G20CrNiMo	0.17∼0.23	0.15∼0.40	0.60∼0.90	≦0.030	≦0.030	0.40∼0.70	0.35∼0.65	0.15∼0.30	
		G20CrNi2Mo	0.17∼0.23	0.15∼0.40	0.40∼0.70	≦0.030	≦0.030	1.60∼2.00	0.35∼0.65	0.20∼0.30	SNCM420
		G20Cr2Ni4	0.17∼0.23	0.15∼0.40	0.30∼0.60	≦0.030	≦0.030	3.25∼3.75	1.25∼1.75	—	
		G10CrNi3Mo	0.08∼0.13	0.15∼0.40	0.40∼0.70	≦0.030	≦0.030	3.00∼3.50	1.00∼1.40	0.08∼0.15	
		G20Cr2Mn2Mo	0.17∼0.23	0.15∼0.40	1.30∼1.60	≦0.030	≦0.030	≦0.30	1.70∼2.00	0.20∼0.30	

Table 13.3 Chemical composition of high-speed steel

Standard		Chemical composition (%)											
		C	Si	Mn	P	S	Cr	Mo	V	Ni	Cu	Co	W
AMS	6491 (M50)	0.77 to 0.85	Max. 0.25	Max. 0.35	Max. 0.015	Max. 0.015	3.75 to 4.25	4.00 to 4.50	0.90 to 1.10	Max. 0.15	Max. 0.10	Max. 0.25	Max. 0.25
	5626	0.65 to 0.80	0.20 to 0.40	0.20 to 0.40	Max. 0.030	Max. 0.030	3.75 to 4.50	Max. 1.00	0.90 to 1.30	—	—	—	17.25 to 18.25
	2315 (M50NiL)	0.11 to 0.15	0.10 to 0.25	0.15 to 0.35	Max. 0.015	Max. 0.010	4.00 to 4.25	4.00 to 4.50	1.13 to 1.33	3.20 to 3.60	Max. 0.10	Max. 0.25	Max. 0.25

Table 13.4 Chemical composition of stainless steel

Standard	Code	Chemical composition (%)						
		C	Si	Mn	P	S	Cr	Mo
JIS G 4303	SUS440C	0.95 to 1.20	Max. 1.00	Max. 1.00	Max. 0.040	Max. 0.030	16.00 to 18.00	Max. 0.75
AISI	440C	0.95 to 1.20	Max. 1.00	Max. 1.00	Max. 0.040	Max. 0.030	16.00 to 18.00	Max. 0.75

Table 13.5 Comparison table of main material components of each country (machine structural carbon steel)

Country name	Standard name	Code	Main chemical composition (%)								Equivalent/ approximate steel of JIS
			C	Si	Mn	P	S	Ni	Cr	Mo	
Japan	JIS G 4051 (2016)	S45C	0.42～0.48	0.15～0.35	0.60～0.90	≦0.030	≦0.035	≦0.20	≦0.20	—	
		S53C	0.50～0.56	0.15～0.35	0.60～0.90	≦0.030	≦0.035	≦0.20	≦0.20	—	
		S55C	0.52～0.58	0.15～0.35	0.60～0.90	≦0.030	≦0.035	≦0.20	≦0.20	—	
USA	AISI A29/29M (2015) SAE J403 (2014)	1045	0.43～0.50	—	0.60～0.90	≦0.040	≦0.050	—	—	—	S45C
		1046	0.43～0.50	—	0.70～1.00	≦0.040	≦0.050	—	—	—	S45C
		1050	0.48～0.53	—	0.60～0.90	≦0.040	≦0.050	—	—	—	S50C
		1053	0.48～0.55	—	0.70～1.00	≦0.040	≦0.050	—	—	—	S53C
		1055	0.50～0.60	—	0.60～0.90	≦0.040	≦0.050	—	—	—	S55C
France/ Germany	NF EN 10083-1,2 (2006) · DIN EN 10083-1,2 (2006)	C45	0.42～0.50	≦0.40	0.50～0.80	≦0.045	≦0.045	≦0.40	≦0.40	≦0.10	S45C
		C45E	0.42～0.50	≦0.40	0.50～0.80	≦0.035	≦0.035	≦0.40	≦0.40	≦0.10	S45C
		C45R	0.42～0.50	≦0.40	0.50～0.80	≦0.035	0.02～0.04	≦0.40	≦0.40	≦0.10	S45C
		C55	0.52～0.60	≦0.40	0.60～0.90	≦0.045	≦0.045	≦0.40	≦0.40	≦0.10	S55C
		C55E	0.52～0.60	≦0.40	0.60～0.90	≦0.03	≦0.035	≦0.40	≦0.40	≦0.10	S55C
		C55R	0.52～0.60	≦0.40	0.60～0.90	≦0.03	0.02～0.04	≦0.40	≦0.40	≦0.10	S55C
China	GB/T 24595 (2009)	45	0.42～0.50	0.17～0.37	0.50～0.80	≦0.025	≦0.025	≦0.30	≦0.25	≦0.10	S45C
	GB/T 699 (2015)	50Mn	0.48～0.56	0.17～0.37	0.70～1.00	≦0.035	≦0.035	≦0.30	≦0.25	—	S53C
		55	0.52～0.60	0.17～0.37	0.50～0.80	≦0.035	≦0.035	≦0.30	≦0.25	—	S55C

Table 13.6 Physical property values of bearing materials

Steel type	Density ρ (g/cm³)	Longitudinal elasticity factor E(GPa)	Linear expansion coefficient (×10⁻⁶/°C)	Thermal conductivity (W/m·°C)	Specific heat (J/kg·°C)	Remarks
SUJ2	7.83	208	12.5	46	468	Quenching and tempering
SCr420	7.84	208	12.6	47	(470)	Quenching and tempering
SCM420	7.85	208	12.5	45	(470)	Quenching and tempering
SNCM420	7.85	208	12.0	44	(470)	Quenching and tempering
M50	7.85	210	11.4	25.0	460	Quenching and tempering
SUS440C	7.75	205	10.6	24.2	460	Quenching and tempering
SPCC	7.86	206	11.5	59	470	Annealing (not hard)
SUS304	7.93	193	17.3	16.3	500	Annealing
Chrome steel	7.84	206	11.2	42～50	465	0.09～0.25C, 0.55～1.5Cr
Special extra-mild steel	7.86	209	11.6	58.2	473	C<0.08
Extra-mild steel	7.86	206	11.4	58.7	475	0.08～0.12C
Mild steel	7.86	207	11.2	55.2	477	0.12～0.2C
Semi-hard steel	7.85	207	10.8	46.5	485	0.3～0.45C
Hard steel	7.84	205	10.7	44.1	489	0.4～0.5C
High carbon steel	7.82	201	10.2	40.1	510	0.8～1.6C
Mid carbon steel	7.8	202	10.7	38	460	0.5C
Silicon nitride	3.24	308	3.0	20	680	Si_3N_4
Six-four brass	8.4～8.8	103～105	18.4～20.8	81～121	377～381	(Equivalent to CAC301)

Note: ( ) indicates reference values.

Table 13.7 Mechanical property values of bearing materials

Steel type	Hardness (HV)	Yield point (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction of area (%)	Charpy impact value (J/cm²)	Remarks
SUJ2	700～750	(≧1176)	(≧1617)	≦0.5	—	(5～8)	Quenching and tempering
SCr420	250～340	—	≧830	≧14	≧35	≧49	Quenching and tempering
SCM420	275～370	(≧700)	≧930	≧14	≧40	≧59	Quenching and tempering
SNCM420	310～395	—	≧980	≧15	≧40	≧69	Quenching and tempering
SNCM815	330～395	—	≧1050	≧12	≧40	≧69	Quenching and tempering
SPCE	≦100	—	≧270	≧32～43	—	—	Annealing
SUS304	≦195	Proof stress≧206	≧520	≧40	≧60	—	Annealing
S10C	115～160	≧206	≧314	≧33	—	—	900°C furnace cooling
S25C	130～190	≧265	≧411	≧27	—	—	850°C furnace cooling
S45C	175～240	≧343	≧569	≧20	—	—	Quenching and high-temperature tempering
S53C	190～270	≧392	≧647	≧15	—	—	Quenching and high-temperature tempering
Silicon nitride	1500	—	Bending≧300	—	—	—	Si_3N_4
Six-four brass	100～150	—	≧430	≧20	—	—	(Equivalent to CAC301)

Note: Mechanical properties are largely influenced by the sample size. ( ) indicates reference values, and - indicates unknown values.

Table 13.8 Chemical composition of steel plate for pressed cages and carbon steel for machined cages

	Standard	Code	Chemical composition (%)						
			C	Si	Mn	P	S	Ni	Cr
Pressed steel cage	JIS G 3141	SPCC	—	—	—	—	—	—	—
	JIS G 3131	SPHC	—	—	—	Max. 0.050	Max. 0.050	—	—
	BAS 361	SPB2	0.13～0.20	Max. 0.04	0.25～0.60	Max. 0.030	Max. 0.030	—	—
	JIS G 4305	SUS304	Max. 0.08	Max. 1.00	Max.2.00	Max. 0.045	Max. 0.030	8.00～10.50	18.00～20.00
Machined cage	JIS G 4051	S25C	0.22～0.28	0.15～0.35	0.30～0.60	Max. 0.030	Max. 0.035	—	—

Table 13.9 Chemical composition of high-strength cast brass for machined cages

Standard	Code	Chemical composition (%)							Impurities	
		Cu	Zn	Mn	Fe	Al	Sn	Ni	Pb	Si
JIS H 5120	CAC301	55.0 to 60.0	33.0 to 42.0	0.1 to 1.5	0.5 to 1.5	0.5 to 1.5	Max. 1.0	Max. 1.0	Max. 0.4	Max. 0.1

Table 13.10 Representative characteristics of resins used for cages

		Polyamide		Polyphenylene sulfide	Polyetheretherketone	Fabric-reinforced phenolic resin
		66	46	PPS	PEEK	
Type		Crystalline thermoplastics	←	←	←	Thermosetting resin
Melting point °C		265	295	285	343	—
Glassy-transition temperature °C		66	78	88	143	—
Maximum continuous operating temperature°C		120	150	230	260	—
Price 1 (low) to 5 (high)		1	2	3	5	4
Characteristics	Formability	◎	○	○	○	×
	Toughness	◎	◎	△	○	○ to △
	Strength	○	○	○	◎	△
	Oil resistance	○ to △	○ to △	◎	◎	○
	Moisture/water absorption	Large	Large	Slight	Slight	Small
Comprehensive evaluation		The property is generally stable.	The formability is slightly poor compared with polyamide 66, but the heat resistance is high.	The water absorbency is low, and the oil resistance and heat resistance are high.	Polyetheretherketone has properties necessary for cages but is expensive.	The lubricity is high, but complicated shapes cannot be machined.
Applications		All-purpose	Temperature higher than polyamide 66	Applications that require oil resistance and heat resistance higher than polyamide	High-speed bearings for high-temperature and high-speed machine tools	High-speed angular contact ball bearings for machine tools

Note: ◎ Excellen ○ Good △ OK × Poor

Table 13.11 Representative characteristics of rubber materials used for seals

Rubber type		Nitrile rubber	Acrylic rubber	Fluorinated rubber
Abbreviation		NBR	ACM	FKM
Characteristics	Elongation	○	○	△
	Compression set	◎	×	○
	Wear resistance	◎	○	◎
	Aging resistance	○	◎	◎
	Weather and ozone resistance	△	◎	◎
	Water resistance	◎	△	◎
	Operating temperature range °C	−20 to 140	−15 to 150	−30 to 230
Comprehensive evaluation		The oil resistance, heat resistance, and wear resistance are high. It is widely used as rubber seals.	It is used at application temperature higher than that of NBR. It is easily swollen in ester oil. An ester-oil resistant grade is also available.	It is expensive. It has excellent heat resistance and chemical resistance but easily affected by urea grease.

Table 13.12 Physical properties of shaft and housing materials

Parts	Material	Density ρ (g/cm^3)	Hardness (HV)	Longitudinal elasticity factor E(GPa)	Linear expansion coefficient (×10^{-6}/°C)	Thermal conductivity (W/m·°C)	Specific heat (J/kg·°C)	Remarks
Shaft	S25C	7.86	130	212	11.1	53	470	Annealing
	S45C	7.85	230	205	(11.9)	(41)	460	Thermal refining
	SS400	7.86	—	205	11.3	50	460	
	SCM415	7.85	300	200	11.0	42	460	Thermal refining
	SCM425	7.85	320	208	12.8	45	470	Thermal refining
	SCM440	7.85	340	205	12.0	41	460	Thermal refining
	SNCM439	7.85	340	208	12.0	44	470	Thermal refining
Housing	FC200	7.2	≧240	100	10～11	43	530	Gray cast iron
	FC250	7.3	≧250	100	10～11	41	530	
	FCD450	7.2	150～220	154	12.0	34	620	Spherical graphite cast iron
	FCD500	7.2	160～240	154	11.0	30	—	
	FCD700	7.2	190～320	154	10.0	26	—	
	ADC12	2.7	(HRB54)	71	21.0	96	(900)	Al-Si-Cu alloy
	SUS304	8.0	≦200	197	17.3	16	500	Austenitic stainless steel
	SUS410	7.8	≧170	204	10.8	(25)	460	Martensitic stainless steel
	SUS410L	7.8	(200)	204	10.8	(25)	—	Ferritic stainless steel

Note: Inequality signs indicate standard values. ( ) indicates reference values.

Table 13.13 Mechanical properties of shaft and housing materials

Parts	Material	Hardness (HV)	Yield point (MPa)	Tensile strength (MPa)	Elongation (%)	Remarks
Shaft	S25C	180	≧270	≧440	≧27	Normalizing
	S45C	240	≧345	≧570	≧20	Normalizing
	SS400	—	(215)	≧400	≧17	Structural rolled steel
	SCM425	320	670	800	15	Thermal refining
	SCM440	340	835	980	17	Thermal refining
	SNCM439	340	900	980	18	Thermal refining
Housing	FC200	≦235	—	≧200	—	Separate casting sample Gray cast iron
	FC250	≦250	—	≧250	—	
	FCD350-22	≦160	≧220	≧350	≧22	Spherical graphite cast iron Separate casting sample
	FCD450-10	150～220	≧250	≧450	≧10	
	FCD500-7	160～240	≧320	≧500	≧7	
	FCD700-2	190～320	≧420	≧700	≧2	
	ADC12	(HRB54)	150	310	3.5	Al-Si-Cu alloy
	SUS304	≦200	(205)	(520)	≧40	Austenitic stainless steel
	SUS410	≧170	(345)	(540)	≧25	Martensitic stainless steel
	SUS410L	≦200	(195)	(400)	≧20	Ferritic stainless steel

Note: Inequality signs indicate standard values. ( ) indicates reference values.