SKF

BEARING COATINGS

Overview

TBO	MnPh	ZnPh, ZnCaPh	TGO		
NoWear®	NoWear® Plus	DLC	CrN	MoS_2:ME (PVD)	
Zinc	ZnFe	ZnNi	Zn flame spray	Zn cold spray	Zinc flake
Hard chromium	TDC				
Nickel	NiP	NiP+FR	Hybrid Ni+Cr		
Copper	Silver	Tin			
HFC	C3H	C5MH	UV cure paint	Paint for housings	
Hydrogen protection coating	Chemical protection coating				
INSOCOAT					
WS_2 / MoS_2					

Contents

The potential of surface refinement

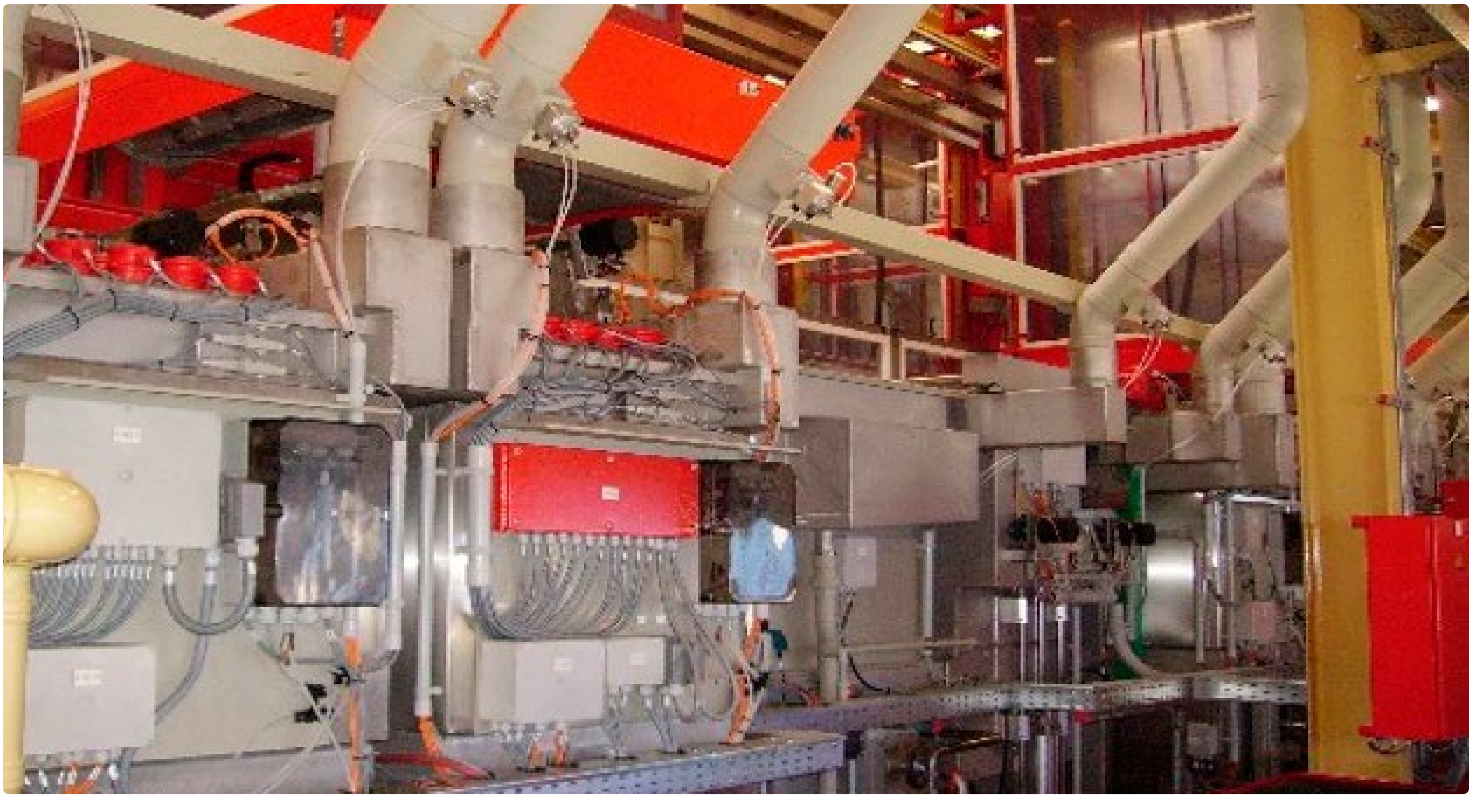
– an introduction to coatings

Application demands and operating conditions of rotating machinery are extremely diverse. To achieve the best performance for an application there are many different parameters to consider: dimensions, weight, rotational speeds, load ratings, sealing and lubrication, to name a few.
In order to satisfy a variety of operating conditions and application performance requirements, SKF manufactures virtually every type of ball and roller bearing, offering them in various cross sections.

However, certain applications and operating environments present challenges that standard bearing designs are unable to meet. To help maximize service life and performance of a bearing, coatings can offer a solution. Coatings are widely used as surface treatments to adapt different bearing components to more extensive requirements. They can impart a large variety of properties, including:

- Energy saving in operation
- Increased or reduced friction
- Hydrogen barrier
- Corrosion resistance in humid environment
- Corrosion resistance in chemically aggressive environment
- Wear resistance
- Surface hardness modification
- Surface roughness change
- Sliding and emergency running properties
- Increased or reduced lubricant or fluid adhesion (wetting properties)
- Oleophobic or hydrophobic properties
- Electrical insulation
- Aesthetic requirements

Phosphating plant at SKF



Chemical treatment plant at SKF

To address these specific requirements, we offer a number of different specialty coatings: galvanic layers, chemically produced layers, thermally sprayed layers, kinetically sprayed layers, melted layers, vacuum deposited layers, dip coat layers and paint layers. They all require completely different and often sophisticated manufacturing approaches. Usually, even a coating readily available on the market needs significant adjustment to make it suitable for the requirements in a bearing application.

The variety of available coating systems and their different functionalities offer a broad range of possibilities. Often a coating refinement can be added to a specific product at the customer's request. In sum, a quality product such as an SKF bearing can receive its final enhancement from a well-designed coating to help provide optimum performance and reliability. In challenging cases, we often combine several different coatings in one final product.

Galvanic layers

By immersing workpieces and additional anodes into electrolytes and connecting them to an electric current, a galvanic coating is produced. Chromium (Cr) and zinc nickel (ZnNi) are typical examples of galvanic layers.

For the galvanic coating to work, every workpiece needs stable electrical contact, so each bearing ring must be clamped into a rack or coating tool, increasing the outlay. Small parts, like rollers, can be coated in a rotating drum with bulk contact.

The coating thickness varies with the workpiece geometry. On the edges, the electrical current lines within the fluid are concentrated, giving a thicker coating. Recesses and hidden areas get thinner layers, or no layer at all.

To get a more evenly distributed layer it is possible to optimize anode positions, use shielding plates, use better scattering electrolytes, or take other measures. However, those efforts may be significant, but still not give a uniform coating on all workpiece areas. It may even be impossible to coat some areas.

Coating plant at SKF
Schweinfurt, Germany

Sophisticated hard chromium
anode frames at SKF

Examples of common galvanic layers:

Galvanic zinc (Zn), zinc-iron (ZnFe), zinc nickel (ZnNi):

Layers of pure or alloyed zinc, mostly only 1–10 microns thick, for anti-corrosion purposes or for friction increase.

Hard chromium (Cr), columnar chromium, structured chromium, thin dense chromium (TDC):

Very hard layers. Often used as surface armour to minimize wear. Some variants are tight (dense) and have anti-corrosion properties, some have a surface topography that influences friction. For bearing applications, most coatings are less than 5 microns thick.

Nickel (Ni):

By using nickel, a very tight (dense) layer is formed that gives good protection against corrosion and delivers chemical resistance, as long as the coating is undamaged. Nickel bonds well to steel and is also used as undercoat for other layers.

Copper (Cu), tin (Sn), silver (Ag):

Soft metallic materials that, for example, are used for cage coatings and that can have similar properties as dry lubricants. These coatings are typically in the range of 2 to 15 microns. Copper bonds well to steel and may be used as an undercoat for other layers at low mechanical load.

Chemical protection coating:

Applications with aggressive environments, for example containing ammonia, require passive and shielding coatings which do not degrade in contact with these substances. SKF has developed special coating solutions which withstand these challenges.

Galvanic coating plant at SKF

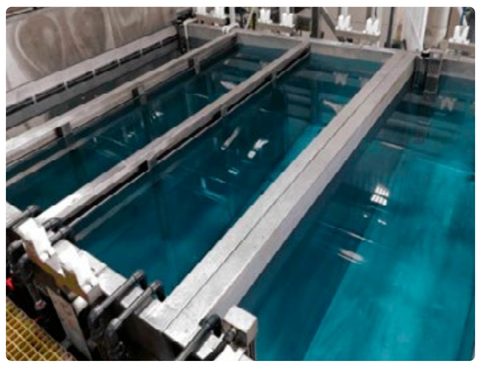
Chemically produced layers

For coatings that are produced by immersing workpieces into chemical fluids, the layer is chemically formed on all workpiece surfaces that come in contact with the fluid.

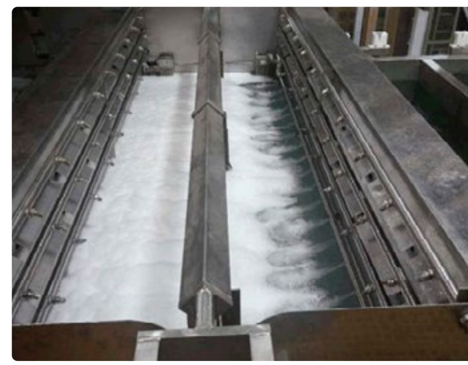
The thickness of the coating is not significantly influenced by workpiece geometry, and it is easy to batch workpieces in racks, in workpiece carriers or in drums as no electrical contact is required. This makes chemically produced layers ideal for mass production, and the first choice for reliable and repeatable large volume coatings at moderate cost.

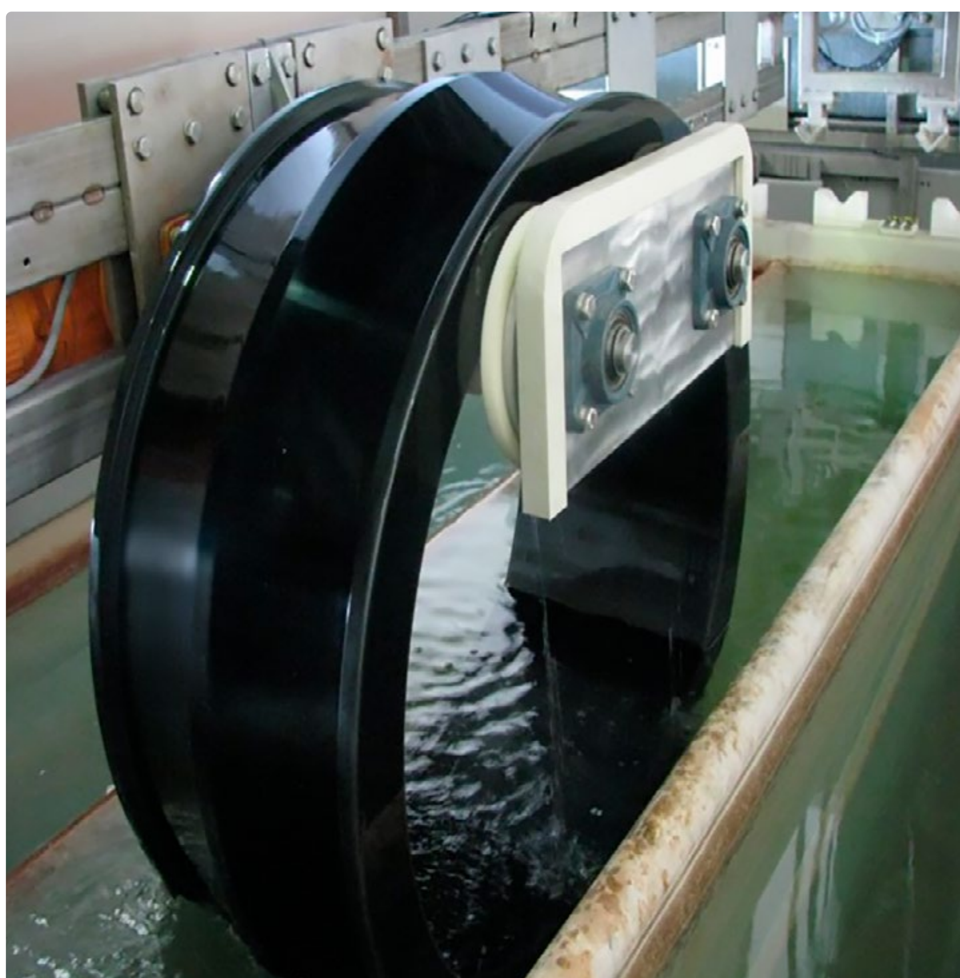
Sometimes galvanic layers can be modified and produced chemically instead. For example, a galvanic nickel (Ni) layer can for some applications be replaced by a similar layer with phosphorus (NiP) that can be created without external current (electroless nickel).

Water rinsing tanks in an SKF coating facility



Chemical processing tank in an SKF coating facility





Tribological black oxide on an SKF bearing ring from Gothenburg

Examples of common chemically produced layers:

Tribological black oxide (TBO):

Tribological black oxide is the most common coating for general bearing applications. It is an alkaline surface treatment with only 1 micron oxidation depth, leaving all dimensions unchanged, and delivering numerous advantages for bearing performance. It is not identical with DIN or ISO black oxide as these treatments can be detrimental for bearings.

Tribological grey oxide (TGO):

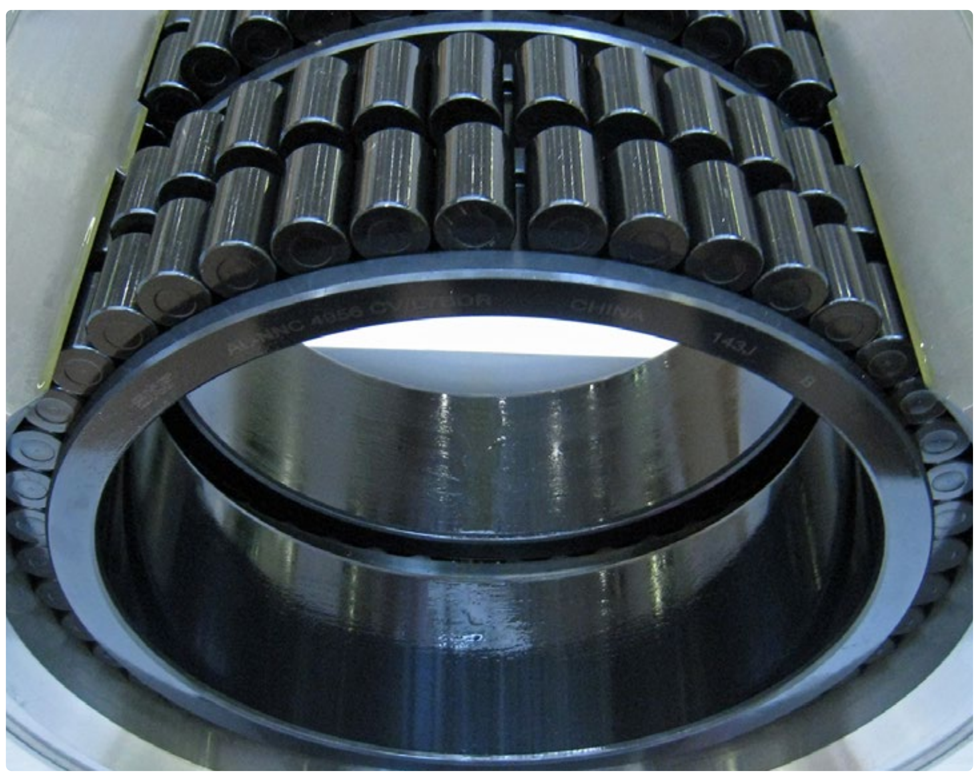
There are other coating approaches which can deliver a surface oxygen content even higher than with TBO and can have less energy consumption and less waste for optimised environmental protection.

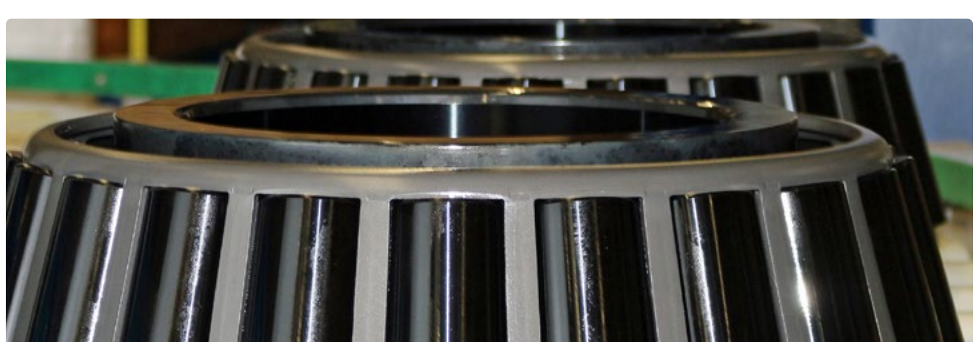
Manganese phosphate (MnPh), zinc phosphate (ZnPh), zinc calcium phosphate (ZnCaPh):

Phosphates were originally limited to sliding applications (plain bearings and cages) but can also be applied to rolling bearings. The soft and porous layer is a very good lubricant reservoir, especially MnPh. The protection level against humidity corrosion is higher than with TBO. MnPh can be widely varied in thickness, grain form and substrate anchoring, and can even be sealed, to be tailored for the specific application.

Nickel-phosphorus (NiP):

NiP is a chemically produced nickel coating. By changing the amount of phosphorus, hardness and corrosion protection can be adjusted. The resulting layer is tight and resistant with a high protection level. It can be further modified with thermal post-treatment or by including soft or hard particles in the layer. A nickel strike bond layer (pure Ni) is often used to enhance the bonding of the coating on steel surfaces.





Combination layers

To get the best product properties, it might sometimes be necessary to combine different coatings. Not only with different coatings on rings and rolling elements, but by getting two different coatings on different surfaces of the same ring. It is also possible to apply the same coating with defined but different thicknesses on different surfaces of the same ring or on different parts of the bearing.

The requirements for functional surfaces, like the raceways, often differ from those on the outside surfaces of the bearing. In these cases, using only one coating may be a compromise, and it can be better to combine the best surface conditions for the functional surfaces with the best surface conditions for the outside surfaces.

Adding a combination of coatings to the same workpiece is a complex approach, and normally limited to certain applications.

For example, SKF can offer raceways coated with tribological black oxide (TBO) and outside surfaces coated either with manganese phosphate (MnPh) or with zinc nickel (ZnNi). Other combinations are also possible.

Thermally sprayed layers

Some coatings are produced by thermal spray. This requires the coating material to be in powder (metal or ceramic) or in wire form (metal). The powder material is melted by a heat source (e.g. flame, plasma, high velocity oxygen fuel) and blown towards the workpiece with a pistol-like device. On the workpiece surface, the drops solidify and form a layer.

Thermally sprayed layers are usually thick, with thickness variations due to the application process. In some cases, the porous result may require additional sealing of the coating surface.

The layer mainly adheres to the surface by mechanical clamping, which means that the workpiece surface needs to be roughened prior to the thermal spray, for example by sand blasting. If tight tolerances are required, a mechanical rework of the layer is needed.

Examples of common thermally sprayed layers:

INSOCOAT and other aluminium oxide (Al_2O_3) layers:

Ceramic layers, mainly consisting of aluminium oxide (Al_2O_3) with additional specific additives, that can be used for electrical insulation purposes. Some variants are also useful for outside corrosion protection or chemical protection. They have high wear resistance.

In addition, inner ring raceways of spherical plain bearings can be coated using plasma or high velocity oxygen fuel (HVOF) with fine layers of aluminium oxide, tungsten carbide, copper-based alloys, etc., to reduce friction or wear for dry or lubricated sliding contact.

Zinc (Zn) or zinc-aluminium (ZnAl):

Zinc, applied in the flame spray process, is the classic approach to produce thick layers of zinc without immersion.

Other metals or other ceramics:

The atmospheric plasma spray processes (APS) are mainly used to apply thick layers of armouring materials to workpieces.

INSOCOAT electrically insulating ceramic layer produced by SKF

Zinc flame spray coated SKF bearing for a wind turbine

Kinetically sprayed layers

Similar to thermal spray, the coating raw material comes as powder.

The powder is blown through a Laval nozzle to reach supersonic speed (high-pressure cold spray). When it collides with the workpiece surface, the metal powder welds on to the surface as a tight layer due to its high kinetic energy.

Kinetically sprayed layers are strongly welded to the workpiece, and cannot flake off, even if the surface has not been roughened before being sprayed. The resulting properties of the layer make the method technically more advantageous than thermal spray. Both thermally sprayed layers and kinetically sprayed layers are very thick and can range from 50 microns to several millimetres.

Examples of applicable materials:

Titanium, zinc, copper, aluminium, tin, silver, stainless steel, white metal, bronze, babbitt, various alloys, and even mixtures of metal powders with non-metallic compounds.

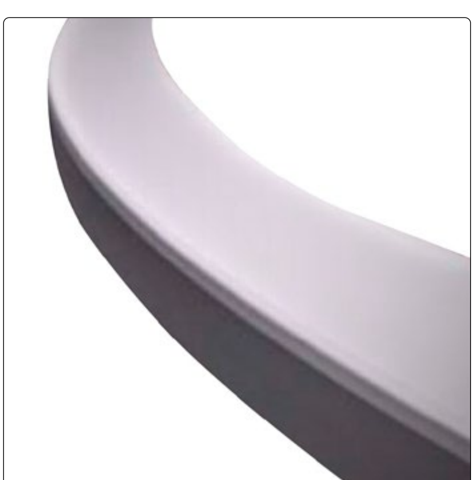
Vacuum deposited layers

These coatings are produced by placing the clean workpiece into a vacuum chamber where a thin and usually extremely hard and wear-resistant layer is vapour-deposited onto the workpiece surface.

There are several ways to form vacuum-deposited layers. In chemical vapour-deposited (CVD) methods, a layer is formed through chemical reactions from gases pumped into the chamber. However, this method often requires temperatures above what is possible for hardened workpieces. Physical vapour deposition (PVD) methods and plasma-assisted chemical vacuum deposition (PACVD) methods are low-temperature alternatives.

In the PVD process, solid targets of the layer material are positioned in the vacuum chamber and the material is vaporized using a physical method like sputtering off by ions or evaporating by an electron beam. The material then condensates on the workpieces, giving them the required layer. Combinations are possible, for example forming CrN by using a Cr target in a nitrogen atmosphere.

The workpieces need to be extremely clean, so in addition to washing and cleaning before the vacuum process, there is also plasma etching in the vacuum chamber. The workpieces are placed on racks in the chamber and are typically rotated. The size of the workpieces is limited to the size of the vacuum chamber. The layer is usually between 1 and 4 microns thick and can consist of several sublayers and alloyed layers (metal doping).



Kinetically sprayed zinc on a large size SKF ring

Examples of commonly used vacuum deposited layers:

NoWear®:

A well-proven SKF solution delivering the advantages of a metal doped diamond-like carbon-based layer deposited by a PVD/PACVD process and customised for bearing raceway applications.

NoWear® Plus:

A NoWear® solution with further customised bonding properties for even higher adhesion, protection and crack resistance.

Diamond-like carbon (DLC):

DLC is the generic name for a group of carbon-based layers with compositions between graphite (sp^2 carbon bonding structure) and diamond (sp^3 carbon bonding structure). They can either include hydrogen (classic, a-C:H) or no hydrogen (a-C, ta-C). The composition influences hardness and other properties. In general, the hardness is very high, and the friction is low. The highest hardness can be achieved by a maximum amount of sp^3 diamond structure (e.g. ta-C), but this reduces the presence of sp^2 carbon structure and weakens the dry lubrication side effects. An advanced approach is to design a more complex coating consisting of multilayers with alternating or different amounts of sp^3, sp^2, hydrogen, and also in some cases, metals. A unique feature of DLC coatings is their running-in characteristic. Although they are very hard, a small portion of the coating surface transforms into a low-friction graphitic contact zone that is transferred onto the counter surface. This mechanism protects the counter steel surfaces that otherwise would be damaged by the harder coating. Combined with the hardness, this effect results in an ideal solid lubrication condition.

Metal-containing DLC (a-C:H:Me, for example WC/C):

The “alloying” of DLC layers with various elements, mainly metals, can adjust and improve their properties. There is no sharp transition line if these are still called DLC.

Ti-doped MoS_2:

This solution consists of a Ti-doped MoS_2 layer with a Ti bonding layer on the steel substrate, deposited by a PVD sputtering. The coating is hard and provides low friction in dry, vacuum, and clean room environments.

Chromium nitride and chromium carbonitride:

Layers with high hardness that protect the surface against abrasive wear at an acceptable friction level. May run against NoWear® coated surfaces.

Titanium nitride and titanium aluminium nitride:

Layers known from drilling and milling tools that have a very high hardness and wear resistance, but also a significantly higher friction that is not applicable to raceways.

Hydrogen protection coating:

Hydrogen can be detrimental if it enters the steel. Therefore, SKF has developed specific coating solutions to block hydrogen permeation.

SKF bearings with NoWear® coated rolling elements

SKF rolling element surrounded by plasma in a vacuum chamber

Paint layers

Coatings can also be applied as paint layers. The most common variant is to roughen the workpiece surface by sand blasting and apply one or several layers of epoxy paint by spray, roller or brush.

If the workpiece surface must not be sand blasted, polyurethane systems deliver superior adhesion compared to epoxy.

Paint can be 1K or 2K (1 component or 2 component) or even humidity cured. To reach chemical resistance, curing requires a chemical reaction and not only the evaporation of solvents.

Special variants of paint are UV-cured, or applied electrolytically in an immersion tank (KTL, cataphoretic).

A paint layer can also be added as baking varnish, where a powder is sprayed onto the surface and then melted to form a paint layer.

Zinc flake or aluminium flake coatings are often also addressed as paintlike. Sometimes zinc flake is misunderstood as a zinc coating, but the zinc flakes are bonded together by an organic or inorganic matrix. The material is applied by spray or immersion and then needs to be heat cured.

Examples of paint layers can be seen on some types of SKF large size wind turbine bearings, where humidity-curing polyurethane formulas are applied to the degreased ground steel without prior sand blasting for the purpose of corrosion protection. Some protection levels are certified to last more than 15 years under very corrosive maritime environments.

C3H:

This is the most common variant for painted outer surfaces of SKF large size main shaft bearings.

The corrosion protection level is certified to be C3H acc. to DIN EN ISO 12944.

This gives medium level protection at moderate effort.

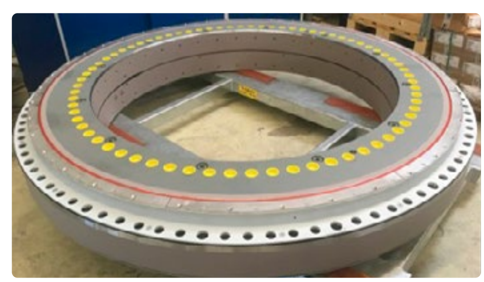
C5MH:

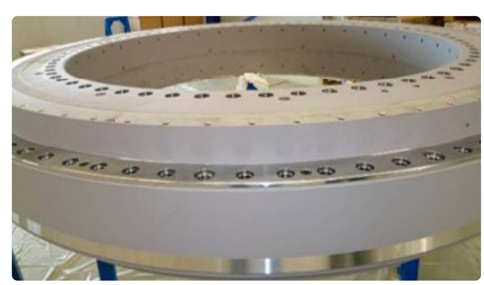
This is the highest possible protection level.

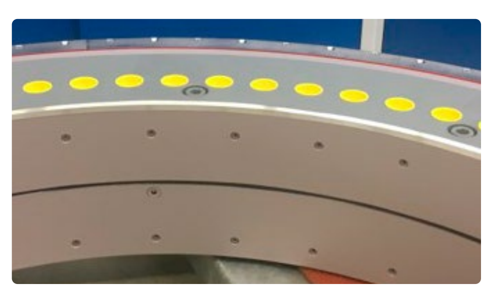
It is certified to be C5MH acc. to DIN EN ISO 12944.

This gives long-time protection even in humid and salty offshore applications.

SKF large size bearings with various painted outer surfaces







Test coating on an SKF large size bearing

SKF High Friction Coating (paint)

A special patented invention, SKF High Friction Coating, is a humidity-curing polyurethane paint with zinc and conductive titanium diboride.

If one paint layer is placed between two flanges, which are then tightened, the hard titanium diboride particles are pushed into both surfaces and locked against relative movement with strongly increased friction. The zinc content will prevent creepage, hinder layer compression under overload, and add anti-corrosion properties.

At disassembly, indicator functions store and reveal whether the previous mounting pressure was correct.

SKF High Friction Coating increases friction and stability of connections to avoid sliding or micro-movements even under lubricated or wet conditions.

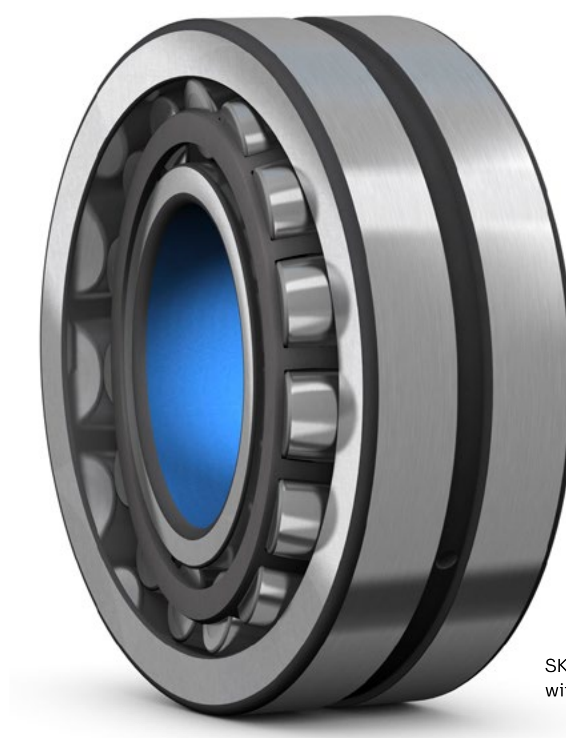
Polymer coatings

Partial surfaces, mainly the bore of inner rings and the outer diameter of outer rings, can be coated with a thick layer of polymer, traditionally polytetrafluoroethylene (PTFE). Curing in a furnace requires a temperature of 150 to 220 °C. Because of the environmental concerns and PFAS regulations, replacement products are applied.

In cases where ring movement in the housing is desired but fretting corrosion must be avoided, a basic approach is to use manganese phosphate or zinc phosphate.

If the requirements are even higher, a PTFE replacement layer (PFAS-free) will deliver long-term and low-friction sliding properties without fretting corrosion propagation.

Ring area with SKF High Friction Coating



SKF spherical roller bearing with a PTFE-coated bore

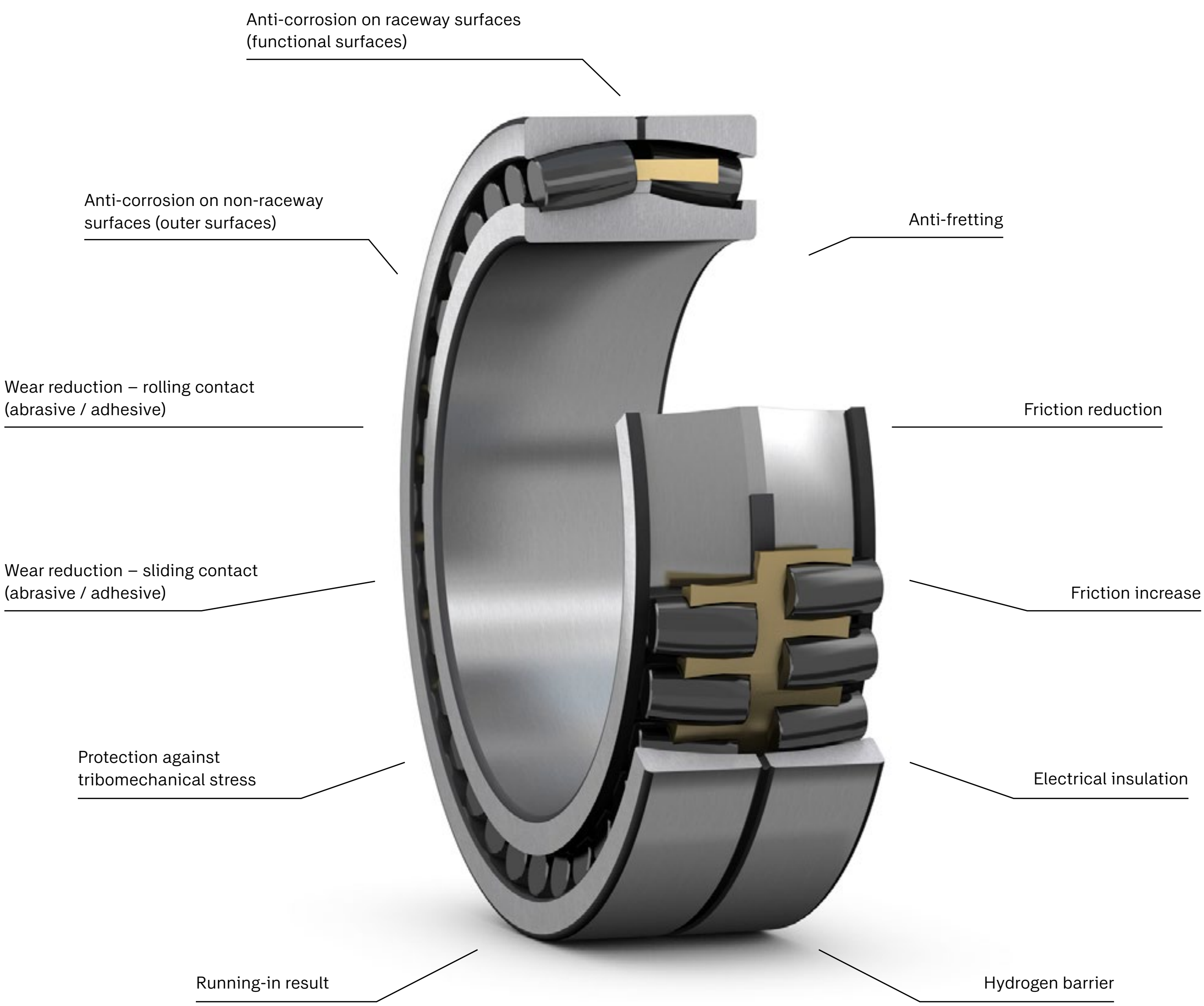
Enhanced bearing performance

– with SKF coatings

SKF offers state-of-the-art coatings for a broad number of applications. Based on precise specifications and strict quality control, all coatings are produced in facilities that often go far beyond usual coating and equipment standards. SKF coatings offer not only increased general performance but also increased durability and higher resistance to environmental influences and harsh operating conditions.

SKF coatings main functions

– classification of coatings depending on the main requirement



SKF bearings coatings overview

– rolling bearings

Anti-corrosion on non-raceway surfaces (outer surfaces)

Chemical protection coating
Zinc flame spray; Zinc cold spray
Paint C3H; Paint C5MH
Zinc flake
Zn; ZnFe; ZnNi
Ni; NiP
Hard chromium; Hybrid Ni+Cr
TDC
MnPh; ZnPh; ZnCaPh
TBO

Wear reduction – rolling contact (abrasive / adhesive)

NoWear®; other PVD/PACVD
TDC
TBO
WS_2; MoS_2
MnPh; ZnPh; ZnCaPh
Zn; ZnFe; ZnNi
Ni; NiP

Wear reduction – sliding contact (abrasive / adhesive)

Hard chromium; Hybrid Ni+Cr
TDC
NoWear®; other PVD/PACVD
Ni; NiP; NiP+FR
MnPh; ZnPh; ZnCaPh
(PTFE)
Copper; Silver, Tin
WS_2; MoS_2
TBO

Protection against tribomechanical stress

NoWear®; other PVD/PACVD
TDC
TBO
MnPh; ZnPh; ZnCaPh

Anti-corrosion on raceway surfaces (functional surfaces)

Chemical protection coating
Zn; ZnFe; ZnNi
Ni; NiP
Hard chromium; Hybrid Ni+Cr
TDC
MnPh; ZnPh; ZnCaPh
NoWear®; other PVD/PACVD
TBO

Anti-fretting

(PTFE)
MnPh; ZnPh; ZnCaPh
WS_2; MoS_2
NoWear®; other PVD/PACVD
TBO

Friction reduction

(PTFE)
WS_2; MoS_2
NoWear®; other PVD/PACVD
TDC
TBO
MnPh; ZnPh; ZnCaPh

Electrical insulation

INSOCOAT
(PTFE)
MnPh

Running-in result

TBO
WS_2; MoS_2
MnPh; ZnPh; ZnCaPh

Friction increase

HFC
Zinc flame spray; Zinc cold spray
Zn; ZnFe; ZnNi
INSOCOAT

Hydrogen barrier

Hydrogen protection coating
TBO
NiP

– plain bearings

Anti-wear (without lubrication)
PVD-TiN
PVD-DLC
PVD-CrN
HVOF-WC/Co
HVOF-Alumina
Hard chromium

Anti-wear (with lubrication)
MnPh
Hard chromium
Plasma HVOF Cu alloy
PVD-TiN
PVD-DLC
PVD-CrN
HVOF-WC/Co

Anti-corrosion
ZnNi
ZnFe
NiP
Hard chromium; Hybrid Ni+Cr
MnPh (lubricated)

Tribological black oxide (TBO)

SKF competence

SKF was the first to understand and analyse the optimum black oxide (BO) layer properties and adjust their processes accordingly towards TBO (investigation since 2006). SKF delivered large size bearing rings with TBO based on a new rotational process as early as 2011. SKF was the first to judge TBO quality not only by DIN and ISO standards, but also by SEM microscopy. SKF has filed several patents regarding special TBO layers and testing methods (e.g. colour test). The SKF production specifications for TBO are very thorough and go far beyond the DIN and ISO descriptions. Adequate black oxide properties for a rolling bearing are not safeguarded by compliance with the DIN and ISO standards; instead, these could deliver detrimental bearing performance.

Description

Tribological black oxide is a black conversion layer formed when oxygen reacts with the iron in the workpiece to form Fe_3O_4. The coating does not change the dimensions of the workpiece and does not exfoliate. All surfaces are coated, and in a roller bearing usually both rings and the roller set are all coated. For specific needs, it is possible to coat only the rings or only the roller set.

Typical applications and current use

SKF produces TBO variants of tapered roller bearings, cylindrical roller bearings, spherical roller bearings, CARB toroidal roller bearings and ball bearings, but most production is related to tapered roller bearings and cylindrical roller bearings in the medium-size range. The use in wind gearboxes is widely acknowledged, and the use for wind main shaft applications (> 2 000 mm) is becoming more and more common.

In addition, large volumes of small cylindrical roller bearing rollers such as 10 mm diameter are coated with TBO.

Features and benefits

The main advantages of tribological black oxide are related to rolling contacts. Besides improvements to the running-in process, the layer offers moderate positive effects against most known bearing failure modes and is a good overall choice to support bearing life. Special additional properties are improved lubricant adhesion and hydrogen barrier.

- Suitable even for high load applications
- Bearing remains fully functionable even if the layer is worn off
- Surface improvement during running-in phase
- Significant friction reduction (after running-in phase)
- Reduction of sliding wear and adhesive wear
- Improved oil adhesion
- Improved surface protection under low-kappa conditions
- Hydrogen barrier
- Reduction of micro-pitting
- Light reduction of smearing and spalling effects
- Reduced risk of surface crack formation
- Surface protection against detrimental oil additives
- Anti-fretting properties
- Light anti-corrosion properties

In recent years, one specific effect of TBO has become more important than all others: its potential to reduce friction. Most bearings coated with TBO show lower friction after running-in, in som cases even by a significant double-digit percentage. This reduction makes a major contribution to energy savings and extending the range of electric vehicles.

Coating process

After being degreased in hot alkaline fluid, the workpieces go through several immersion steps in alkaline black oxide fluids below 150 °C. The process ends with cleaning, dewatering and oil preservation. No acids are used.

At SKF, tribological black oxide coating is done in a full immersion process for rollers and small to medium-sized rings, and in a rotational (partly immersed) process for large size bearing rings. For the smallest rollers, we have a drum process. All process variants apart from the drum process are produced on individual racks with minimized and usually invisible contact points, and without risk of damage.

Tribological black oxide

Property	Value
Layer thickness	0.7–1.5 µm
Layer weight	~5 g/cm^3
Layer grammage	3.5–7.5 g/m^2
Calculation factor g/m^2 ↔ µm	5
Production temperature	< 150 °C
Layer temperature stability	250–300 °C
Layer hardness	Mohs 5.5 – 6.5
Layer conductivity	Not insulating
Hydrogen barrier shielding value	90%
Friction reduction after running-in, oiled, rings rollers coated	–7% (not guaranteed)
General standards Not for bearings	DIN 50938 ISO 11408
Possible diameter range	< 2 500 mm
Possible width range	< 450 mm
Possible weight range	< 1 300 kg
Layer composition	FeO, Fe_2O_3, Fe_3O_4
Nominal composition	Fe_3O_4
Precise composition	$Fe_{11}O_{16}$
DIN EN ISO 9227 NSS salt spray	< 0.5 h (dry)
DIN EN ISO 9227 NSS salt spray	< 70 h (oiled)
DIN EN ISO 6270-2 condense water	48 h (dry)
High resistance against	Oil, grease, solvents, alkaline
No resistance against	Acids, abrasives

Manganese phosphate (MnPh)

Description

The MnPh coating is a grey to black layer that forms when the workpiece is immersed into a manganese phosphating fluid and the iron in the workpiece reacts with the manganese cations and phosphate anions in the fluid. All workpiece surfaces are usually coated, allowing bearing raceways to be left uncoated by shielding or subsequent machining.

Typical applications and current use

SKF mainly applies MnPh to plain bearings and cages, and on roller bearings with specially designed processes. The coating is most common in the small to medium-size range and the use of MnPh in sliding applications is widely acknowledged.
In some markets, the use of MnPh-coatings increases in wind main shaft applications (e.g. 2 000 mm for cages) and in metal industry applications (e.g. 1 200 mm for rings).

Features and benefits

- Suitable for sizes up to 2 m (bearing rings)
- Significantly improved smearing resistance
- Improved micro-pitting resistance
- Emergency lubrication properties
- Friction reduction (after running-in phase)
- Reduction of detrimental water-in-oil effects
- Improved oil adhesion
- Protection under low-kappa and poor lubrication conditions
- Good corrosion protection (oiled condition)
- Anti-wear and anti-fretting properties
- Electrical insulation properties

Coating process

The workpieces are degreased in hot alkaline fluid, followed by several immersion steps including activation and acidic manganese phosphating fluid, all below 100 °C. The process ends with cleaning, drying and preservation. The layer pores can be filled with oil, grease, wax, inhibitors, sealants or dry lubricants.

SKF carries out MnPh-coating in a full immersion process for rings and cages up to large sizes.

Manganese phosphate

Property	Value
Layer thickness	2–15 µm (raceways < 5 µm)
Layer density	~2 g/cm3
Layer grammage	4–30 g/m2
Production temperature	90–98 °C
Layer temperature stability	< 200 °C
Layer conductivity	Insulating
Layer hardness	< 100 HV
General standards Not for bearings	DIN EN ISO 9717
Possible diameter range	< 2 200 mm (cages) < 1 300 mm (rings)
Possible width range	< 350 mm (rings)
Possible weight range	< 400 kg (rings)
Nominal composition	$Mn_5H_2(PO_4)_4$
Precise composition	$(Mn,Fe)_5(PO_4)_2(PO_3OH)_2$
DIN EN ISO 9227 NSS salt spray	< 1.5 h (dry)
DIN EN ISO 9227 NSS salt spray	< 72 h (oiled, layer <5 µm)
Resistance against	Oil, grease, wax, solvents
No resistance against	Alkali, abrasives

Zinc (calcium) phosphate (ZnPh, ZnCaPh)

Description

The ZnPh or ZnCaPh is a light grey to medium grey layer that forms when the workpiece is immersed into a zinc or zinc calcium phosphating fluid and the iron in the workpiece reacts with the zinc (and calcium) cations and phosphate anions in the fluid. All workpiece surfaces are usually coated, allowing bearing raceways to be left uncoated by shielding or subsequent machining.

Typical applications and current use

SKF mainly applies ZnPh and ZnCaPh on roller bearings in railways. ZnPh is preferred when a pure anti-corrosion function is required, and if calcium is added, as in ZnCaPh, the layers are smoother and thinner with finer grains, which means that ZnCaPh is more applicable for raceways. Most bearings with ZnPh or ZnCaPh are in the medium size range.

Features and benefits

- Bearing remains functionable even if the layer is worn off
- Some resistance to sub-surface fatigue
- Good corrosion protection (further increased with oil, grease, wax and inhibitors)
- Anti-wear and anti-fretting properties (rust and wear protection also between bearing and housing)
- Calcium allows for very fine grains and smooth, thin and precise layers
- Friction reduction
- Layer can be used as bonding layer underneath a paint layer

Coating process

The workpieces are degreased in hot alkaline fluid, followed by several immersion steps with or without activation, and acidic zinc or zinc calcium phosphating fluid, all below 85 °C. The process ends with cleaning, drying and preservation. The layer cavities can be filled with oil, grease, wax, inhibitors or dry lubricants. SKF carries out ZnPh and ZnCaPh applications in a full immersion process for medium-sized rings.

Zinc (calcium) phosphate

Property	Value
Layer thickness	2–15 µm (raceways < 5 µm)
Layer density	~2 g/cm^3
Layer grammage	4–30 g/m^2
Production temperature	< 85 °C
Layer temperature stability	< 200 °C
Layer hardness	< 100 HV
Layer conductivity	Low
General standards Not for bearings	DIN EN ISO 9717
Possible diameter range	< 500 mm
Possible width range	< 500 mm
Possible weight range	< 200 kg
Nominal composition	$Zn_3(PO_4)_2$ $CaZn_2(PO_4)_2$
DIN EN ISO 9227 NSS salt spray	< 1.5 h (dry)
DIN EN ISO 9227 NSS salt spray	< 72 h (oiled, layer <5 µm)
Resistance against	Oil, grease, wax, solvents
No resistance against	Alkali, abrasives

Galvanic zinc (Zn)

Description

Galvanic zinc is a thin, relatively soft, silver-coloured layer that is used to increase static friction and corrosion resistance. The zinc layer functions as a sacrificial medium which corrodes first and therefore protects the workpiece surface underneath (cathodic corrosion protection). Zinc layers thinner than 15 µm can be easily achieved in the galvanic process.

Typical applications and current use

Galvanic zinc layers are very common, and for bearings they usually come in an alkaline-produced variant used for anti-corrosion and friction increase. They are normally applied for anti-slip or anti-fretting properties and for corrosion protection on outer surfaces such as bearing outer diameters, bores or housings. In some specific applications, like in a slowly rotating crane, bearing raceways can also be galvanic zinc coated. To meet even higher requirements, it is preferable to use zinc nickel (ZnNi), which delivers higher hardness and better protection than zinc.

Features and benefits

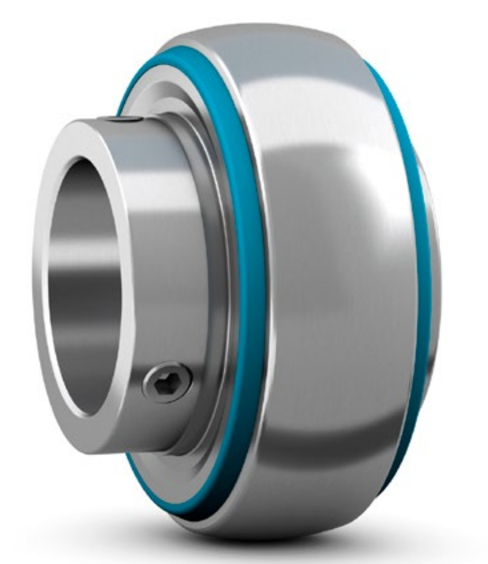
- Cost-efficient, basic and widely available anti-corrosion coating
- The level of protection, friction and colour can be changed with added passivation

Coating process

The workpieces are degreased in hot alkaline fluid. After that, they are etched, and an acidic or alkaline electrolyte is used for the galvanic coating. The process ends with cleaning, passivation and preservation. Passivation is, for example, used to enhance the anti-corrosion effect or to change the colour of the coating.

Galvanic zinc

Property	Value
Layer thickness	3–15 µm
Layer temperature stability	< 120 °C
Layer hardness	< 150 HV
Friction	High (no tolerance)
Production temperature	< 80 °C
DIN EN ISO 9227 NSS salt spray	48 h – 200 h (max. 360 h)
Conductivity	Yes
Hydrogen embrittlement	De-embrittlement may be recommendable



Zinc iron (ZnFe)

Description

The zinc-iron layer is a thin zinc-based alloyed layer, with high friction and corrosion resistance. The zinc layer functions as a sacrificial medium which corrodes first and therefore protects the workpiece surface underneath (cathodic corrosion protection). The ZnFe layer is slightly harder than zinc layers and has better corrosion protection and higher wear resistance thanks to alloying with typically 0.4–0.8% iron.

Typical applications and current use

ZnFe coatings are usually used for corrosion protection in medium to harsh environments on outer surfaces, like bearing outer diameters. By applying the ZnFe layer thinner than 5 µm, bearings can also be delivered with coated raceways.

Alloyed zinc layers were introduced since pure zinc layers corrode faster than required to protect the substrate surface. Zinc-iron was the first alloy to be introduced, followed by the even better zinc nickel alloy. Even with ZnNi on the market, ZnFe is still widely used as an enhancement to pure zinc.

Features and benefits

- Better anti-corrosion properties and chemical resistance than galvanic zinc (but less than ZnNi)
- Higher hardness and wear resistance than galvanic zinc (but lower than ZnNi)
- Thin layers < 5 µm can be applied on raceways
- Less voluminous corrosion products than galvanic zinc

Coating process

The workpieces are degreased in hot alkaline fluid, carefully etched and then immersed in an alkaline electrolytic bath for the galvanic coating. The process ends with cleaning, passivation and preservation.

Zinc iron

Property	Value
Layer thickness	4–10 µm
Layer temperature stability	< 120 °C
Layer hardness	< 180 HV
Friction	High (no tolerance)
Production temperature	< 80 °C
DIN EN ISO 9227 NSS salt spray	< 480 h
Conductivity	Yes
Hydrogen embrittlement	De-embrittlement may be recommendable

Zinc nickel (ZnNi)

Description

The ZnNi layer is a thin zinc-based nickel alloyed layer that is normally metallic grey (depending on passivation). It is formed by galvanic immersion and is harder than zinc and ZnFe layers thanks to alloying with 12–16% nickel. The ZnNi layer has better corrosion protection and higher wear resistance compared to zinc layers.

SKF can either coat rings with uniform thickness on all workpiece surfaces, or coat with defined reduced layer thickness on raceways. This means that the bearing outer surfaces can receive the maximum possible corrosion protection while the inner surfaces (raceways) can receive a lower thickness optimized for functional performance. Alternatively, the raceways can remain uncoated or receive a different coating, for example TBO.

Typical applications and current use

Zinc layers have high friction and good corrosion resistance. The zinc layer acts sacrificially and protects workpieces by layer corrosion. Since pure zinc layers corrode faster than what is required to protect the substrate surface, alloyed zinc layers were introduced. Zinc nickel (ZnNi) is so far the best choice among zinc-based galvanic layers. One can expect around 100 hours Neutral Salt Spray (NSS) resistance per one-micron layer thickness. A 10 µm ZnNi coating can thus deliver around 1000 h NSS protection. ZnNi coatings deliver the lowest hydrogen embrittlement risk among all zinc-based galvanic layers.

The typical application of ZnNi coating is corrosion protection on outer surfaces against harsh environments, for example on bearing outer diameters or threaded joints. By applying the ZnNi layer thinner than 5 µm, even raceways can be coated.

Features and benefits

- Better anti-corrosion properties and chemical resistance than galvanic zinc and ZnFe layers
- Higher hardness and wear resistance than galvanic zinc and ZnFe layers
- Increased operating temperature (compared to zinc layer)
- Low risk of hydrogen embrittlement
- Thin layers (< 5 µm) can be applied on raceways
- No voluminous corrosion products

Coating process

The workpieces are degreased in hot alkaline fluid, carefully etched and then immersed in an acidic or preferably alkaline electrolytic bath for the galvanic coating. The process ends with cleaning, passivation and preservation.

Zinc nickel

Property	Value
Layer thickness	3–10 µm
Layer temperature stability	< 150 °C
Layer hardness	410-450 HV (without tempering)
Friction	0.25-0.3 (against steel)
Production temperature	< 80 °C
Possible diameter range	< 1500 mm
DIN EN ISO 9227 NSS salt spray	360-1000 h
Conductivity	Yes
Hydrogen embrittlement	Low

Zinc flame spray (Zn FS)

Description

Zinc flame spraying gives dull grey silver layers that are thick, porous and rough. They are not welded onto the surface butt "clamped" mechanically onto the surface. Due to the coating process, the layer thickness is usually not very precise or uniform, and the coating may require a final sealant, since it is so porous. By using zinc-aluminium instead of pure zinc, the corrosion protection and mechanical properties can be further improved.

Typical applications and current use

Zinc layers have very high friction and corrosion resistance. The typical application is corrosion protection of the outside of large size main shaft bearings in the wind energy industry. It is also used for housings where a high anti-corrosion effect is required, if zinc is preferred over paint.

Features and benefits

- Suitable for bearings of larger sizes and many geometries without workpiece-dependent tools
- Very good corrosion protection (except in seawater or in contact with chemicals)
- Thick layers with limited thermal impact compared to hot-dip zinc coating
- High friction where desired for mounting

Coating process

The zinc flame spray layer is formed with zinc powder or zinc wire which allows layer thicknesses far beyond what is possible with galvanic zinc. Before the zinc flame spray coating process, the workpiece is sand blasted in order to ensure a rough surface for the zinc to clamp to. The zinc powder or zinc wire is molten and accelerated onto the workpiece surface with compressed air. When the zinc droplets hit the workpiece surface, they become solid again and form the layer. Surfaces that are not to be coated need to be protected with masking or shielding before the flame spray process. After the flame spraying, the porous layer is usually sealed or painted to create a tighter layer structure.

Zinc flame spray

Property	Value
Layer thickness	80–200 µm
Layer temperature stability	< 300 °C
Layer hardness	100–200 HV
Friction	High (no tolerance)
Possible diameter range	> 420 mm
Conductivity	Yes
Hydrogen embrittlement	No
Corrosion resistance according to DIN EN 12944	C5MH

Zinc cold spray (Zn CS)

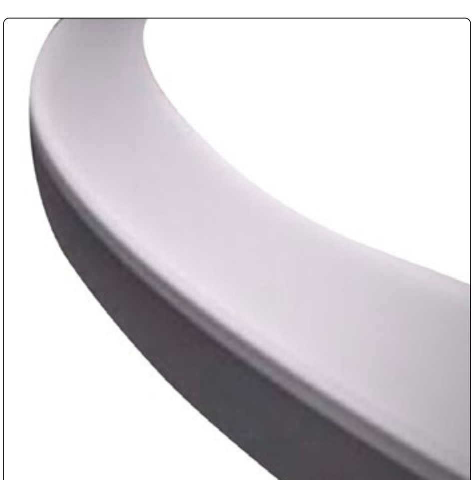
Description

Zinc cold spray coatings are thick, dull silver-coloured layers that give high friction and good corrosion resistance. For zinc spray coatings, the conventional flame spray method is used more often, but it has several disadvantages. It requires sand blasting before coating, gives inaccurate tolerances, has limited adhesion and results in a porous layer. With cold spray coating, these disadvantages are overcome.

Apart from zinc, other metals, like stainless steel and mixed metals, can also be applied with cold spray. They can be coated on workpieces as single layers or in multilayer systems. The precise deposition technology allows not only accurate layers but also partial coating of chosen areas.

Typical applications and current use

Zinc cold spray coating is often used for corrosion protection of the outside of large size main shaft bearings in the wind energy industry, or for housings where a high anti-corrosion effect is required. Zinc cold spray and zinc flame spray are often used for the same applications, but the cold spray method is superior, both in process and result.



Features and benefits

- Suitable for bearings of larger sizes and many geometries without workpiece-dependent tools
- Possible to make a local coating or a circumferential band
- Excellent corrosion protection, better than porous zinc flame spray
- Thick and geometrically precise layers without thermal impact
- High friction where desired for mounting
- Dependable and extremely high adhesion (welded structure, not just intermeshed)
- Low porosity, typically no painting or sealing required
- No need for sandblasting before coating, adheres to ground surfaces, no hard particles, no precision loss
- Little or no shielding and covering needed since adhesion mostly steered by spray angle
- High-pressure fine cleaning after coating with gas stream of 1000 m/s possible
- Multilayer can increase the total chemical resistance.

Zinc cold spray

Property	Value
Layer thickness	100–250 µm (multilayer)
Layer temperature stability	< 300 °C
Layer hardness	< 200 HV
Friction	High (no tolerance)
Possible diameter range	> 420 mm
Conductivity	Yes
Hydrogen embrittlement	No
Corrosion resistance according to DIN EN 12944	> C5MH
Layer bonding strength	50 MPa (depending on substrates and coating parameters)

Coating process

The zinc cold spray layer is formed when zinc powder is sprayed onto the workpiece surface at supersonic speed. The supersonic speed is achieved when particles are brought into a pressurized gas stream which passes through a Laval nozzle. When they hit the workpiece surface, the kinetic energy welds the particles to the surface and to each other, without heating the workpiece. This forced collision results in a high layer density with only a low number of small-sized pores. There is no need for either roughening of the surface before the coating or sealing or painting of the surface afterwards.

As the cold spray process can execute 3D printing of metals and can subsequently coat these printed metal parts with a wide range of protective layers or sliding layers, its use is almost unlimited.

Zinc flake

Description

Zinc flake coatings are corrosion protection coatings that look like dull zinc coatings. The benefit of zinc flake coatings is that there is no risk of hydrogen embrittlement in the substrate, which is unavoidable with galvanic zinc and zinc-alloy coatings. At the same time, the anti-corrosion properties for zinc flake coatings can exceed the levels of galvanic zinc coatings.

Typical applications and current use

Zinc flake coatings are often used as corrosion protection on outer surfaces against harsh environments, for example on housings, flanges, peripheral components, screws or high-tensile bolts. It is not recommended to apply zinc flake coatings on bearing raceways.

Features and benefits

- Excellent anti-corrosion properties
- No risk of hydrogen embrittlement
- Resistance against many solvents
- Friction, chemical resistance and appearance can be adjusted by the topcoat

Coating process

The zinc flake coating is similar to a paint with very high zinc content (up to 85%). It can be active or passive, with the emphasis on cathodic or shielding protection. Passivation can be with or without Cr(VI). The Cr(VI)-free passivation is preferred due to environment, health and safety regulations (EHS) but it offers no self-healing effect.

Lamellar zinc flakes (and sometimes also aluminium flakes) are mixed into a binder, typically silicon containing for example inorganic silicium oxide, to form a paint-like fluid. Cleaned workpieces are either immersed into the fluid or sprayed with the fluid. When immersed, the layer thickness is determined by slow centrifuging or dip-spinning. After application, the layer is cured in a furnace at approximately 180–300 °C. To adjust the friction properties of the layer, more steps can be added after the immersion process.

Zinc flake

Property	Value
Layer thickness: Basecoat Topcoat Total	 6–12 µm 2–6 µm 8–18 µm
Layer temperature stability	< 180 °C
Layer hardness	350–370 HV
Friction coefficient	> 0.15
Production temperature	< 300 °C
Resistant against	Wide range of solvents
DIN EN ISO 9227 NSS salt spray	< 1500 h
Conductivity	Yes
Hydrogen embrittlement	No

Hard chromium (Cr)

Description

Hard chromium is a hard, silver-coloured layer that forms on the required surfaces through an electroplating process. The resulting chromium layer has microcracks, which means limited anti-corrosion properties at low thickness.

Typical applications and current use

Hard chromium plating is widely used in plain bearings under heavy static or alternating loads or shock loads. In a plain bearing, normally the inner ring raceway is hard chromium plated to increase the bearing life. Hard chromium coatings are used in a variety of industries:

- Automotive
- Railways
- Construction
- Agriculture
- Pumps and valves

Features and benefits

- Gives good sliding contact between plain bearing components
- High hardness and high wear resistance
- Reduces friction for sliding applications
- Light anti-corrosion properties
- Light surface protection against environmental influences
- Resistance against abrasive dirt
- Low adhesion for foreign substances to the layer

Coating process

First, the workpieces are degreased in hot alkaline fluid, then electrolytically cleaned, etched, and after that immersed in chromium acid electrolyte. The process ends with cleaning, removal of Cr(VI) and oil preservation.

Hard chromium plating is carried out in a protected and fully automatic environment for small to medium-sized rings. The processes operate without producing wastewater. Processes operating with Cr(VI) are still permitted for necessary applications and SKF has all required permissions. Besides having a closed circle of chemicals via, e.g., vacuum evaporation, there is no waste and the Cr-coated parts do not have any residues of Cr(VI) on their surfaces due to a final chemical conversion.

Hard chromium

Property	Value
Layer thickness	3–15 µm
Layer hardness	800–1 200 HV
Production temperature	< 85 °C
Layer temperature stability	< 400 °C
General standards Not for bearings	DIN EN ISO 6158:2011 DIN EN ISO 4516 DIN EN ISO 2819
Possible diameter range	Max. 550 mm
Possible width range	Max. 270 mm
Possible weight range	Max. 200 kg
DIN EN ISO 9227 NSS salt spray	< 40 h (at 20 um)

Thin dense chromium (TDC)

Description

Thin dense chromium (TDC) differs from hard chromium in its layer structure, properties, and function. While hard chromium has many microcracks and is not seen as a tight and shielding layer, TDC does not have such a crack pattern and is much better in protecting the substrate surface from environmental influences and chemical attacks. Furthermore, the TDC surface structure is tribologically beneficial. It gives low friction and has better lubricant wetting properties than a hard chromium surface.

TDC has a nodular structure with countless small hemispheres protruding from the surface. This characteristic reduces friction and improves its lubrication properties. It is also possible to add a dry lubricant bonded coating on top of TDC layers.

Typical applications and current use

A TDC layer can be applied on bearing raceways and outer surfaces. It is thus preferred for applications where the risk of moisture corrosion and chemicals attacks is high and at the same time high wear resistance and low friction are desired. TDC-coated surfaces can work with TDC-coated counter-surfaces.

Features and benefits

- High hardness and high wear resistance
- Low friction
- Good corrosion resistance
- Accepts wetting with lubricants

Coating process

The workpieces are degreased in hot alkaline fluid, and then either blasted with slightly abrasive powder or etched and then immersed in chromium acid electrolyte (Cr(VI)). Potassium dichromate is used in the process as a catalyst, for example to form a thin chromium layer with the desired surface structure at a lower current density and a shorter coating duration. The process ends with cleaning and preservation.

Thin dense chromium

Property	Value
Layer thickness	2–5 µm
Layer hardness	700–1000 HV (Variants up to 1400 HV)
Production temperature	< 85 °C
Layer temperature stability	> 300 °C
Friction coefficient	0.16 (against steel) 0.12 (against TDC)
DIN EN ISO 9227 NSS salt spray	similar to 440 steel
Conductivity	Low
Hydrogen embrittlement	De-embrittlement may be recommendable (medium to low)

Different variants of TDC layers

Galvanic nickel (Ni)

Description

Nickel electroplating or galvanic nickel is the electrolytic variant of the nickel coating. For technical purposes, the “half gloss” variant is commonly used. The adequate amount of gloss additives balances layer tightness and corrosion resistance with brittleness, gloss and surface levelling. Because of its rather tight structure and high adhesion to substrate surfaces, the nickel layer can also be used as a bonding layer in order to improve anti-corrosion or anti-wear properties. But serious anti-corrosion properties would require thick layers at or above 25 µm to eliminate the effect of pores and impurities.

Galvanic nickel layer is silver-coloured with a slight yellow tendency. It is a pure nickel layer, but its properties are similar to a NiP layer with low levels of phosphorus. The nickel layer resists water, thinned acids and alkalines.

Typical applications and current use

Galvanic nickel layers are not suitable for bearing raceways and are typically used on non-functional surfaces where light anti-corrosion, good anti-wear and high adhesion properties are desired. They are often sublayers for adhesion promotion. For better anti-corrosion properties, high phosphorus NiP should be considered. The geometry of the workpiece should be simple enough for the galvanic process.

Features and benefits

- Good corrosion protection if layer is undamaged and sufficiently thick
- Good wear resistance, especially if tempered
- Conductive
- Resistant to thinned acids and alkalines

Coating process

The workpieces are degreased in hot alkaline fluid, often etched, then immersed in alkaline electrolyte for galvanic coating. The process ends with cleaning and preservation. If layer hardness and wear resistance shall be increased, or hydrogen de-embrittlement is desired, a tempering process step can be considered.

Galvanic nickel

Property	Value
Layer thickness	1–20 (25) µm
Layer temperature stability	> 300 °C
Layer hardness	350–500 HV (up to 1000 HV with thermal treatment)
Friction coefficient	0.20–0.40 (lubr./dry against steel) 0.25–0.45 (lubr./dry against nickel)
Production temperature	< 80 °C
DIN EN ISO 9227 NSS salt spray	< 48 h (at 5 µm thickness)
Conductivity	Yes
Hydrogen embrittlement	De-embrittlement may be recommendable

Electroless nickel (NiP)

Description

Nickel phosphorus (NiP) coating is the chemical variant of galvanic nickel coating. It is also called electroless nickel since it does not require an external electric current. Because the layer is chemically formed, the NiP coating gives geometry-independent layer thicknesses. Special NiP coatings can have soft or hard particles embedded in the layer.

NiP layers are silver-coloured with a slight yellow tendency. There are three variants of NiP layers, with different phosphorus concentrations: low (6%), medium (6 to 9%) and high (9 to 14%). Hardness and wear resistance decrease with increasing phosphorus content, but anti-corrosion properties increase. NiP layers are crack-free and have built-in compressive stresses.

Typical applications and current use

NiP coatings are common in non-raceway applications where a combination of anti-corrosion and anti-wear properties is required. If loads are moderate, NiP layers thinner than 3 µm can also be applied on raceways.

Features and benefits

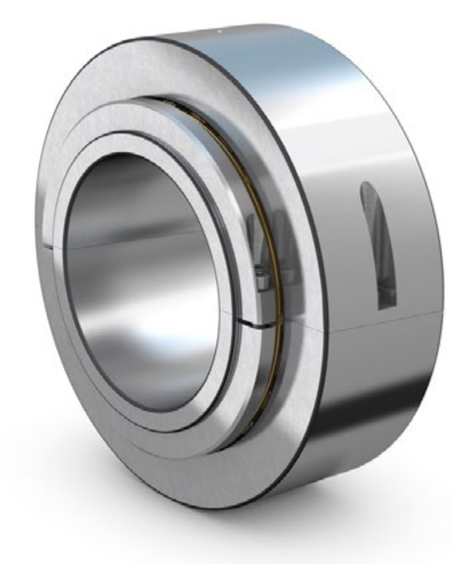
- Uniform layer thickness that follows the workpiece contours
- Good corrosion protection (high phosphorus variants) if the layer is undamaged
- Good wear resistance (low phosphorus variants)
- Simple process compared to electrolytic nickel
- Layers with more than 10% phosphorus are not magnetic

Coating process

The workpieces are degreased in hot alkaline fluid, possibly etched, and then immersed in the coating bath where the layer is formed autocatalytically. Using sodium hypophosphite replaces the necessity of an external electric current. During this reaction, phosphorus is built into the layer to reach the desired concentration. The process ends with cleaning and preservation. For specific applications, a nickel strike before NiP layer formation or a thermal treatment after the NiP layer formation can be applied.

Electroless nickel

Property	Value
Layer thickness	1–25 (50) µm
Layer hardness	
Low phos < 6%	700 HV
Med. phos 6–9%	600 HV
High phos 10–14%	470–600 HV
Tempered	≤ 1000 HV
Friction coefficient	0.25-0.40 (lubr./dry, against steel) 0.25-0.45 (lubr./dry, against nickel)
Production temperature	< 100 °C
Layer temperature stability	< 400 °C
DIN EN ISO 9227 NSS salt spray	240 h (high phosphate at 10 µm) 500 h (high phosphate at 30 µm) 1500 h (high phosphate at 50 µm)
Conductivity	Yes
Hydrogen embrittlement	Low



Electroless nickel with friction reducer (NiP+FR)

Description

Nickel phosphorus (NiP) or electroless nickel delivers hardness, adhesion, and shielding properties, and it offers the possibility to add soft or hard particles to the NiP matrix to change its properties. The typical choice for friction reducer (FR) has been PTFE. PTFE is a linear polymer of carbon and fluorine and does not show a stick-slip effect but provides the layer with a dependable low friction property. A PTFE content of 20–30% (by volume) functions as a dry lubricant.

The grey-coloured NiP+PTFE layer consists of two layers. The first layer, also called the support layer, is a 2–3 µm pure NiP layer and, on top of it, a 5 µm NiP+PTFE is formed to a composite layer as the second layer. The support layer increases corrosion protection and supports adhesion. Typical phosphorus contents of the NiP layer are 8–12%.

Typical applications and current use

Bearings with NiP+FR coating are mainly used in agricultural applications, where ring movement is necessary and anti-corrosion properties are desired. In some cases, NiP+FR coatings are also applied in food industry and noise reduction applications. They are not recommended for use on bearing raceways.

Features and benefits

- Very low friction, self-lubricating (dry lubrication), self-cleaning
- Hydrophobic, no swelling by water
- Metal-like appearance and properties
- Medium to good corrosion resistance
- Noise reduction
- Adhesion reduction
- No stick-slip effects

Electroless nickel with PTFE (other FRs may deviate)

Property	Value
Layer thickness	5–8 (15) µm (whereof 2–3 µm pure NiP as base layer)
Layer hardness	350 HV; up to 550 HV (after thermal treatment)
Friction coefficient	0.15 (against steel) 0.05 (against NiP-PTFE) (lubr./dry, against nickel)
Production temperature	< 90 °C
Layer temperature stability	< 240 °C
DIN EN ISO 9227 NSS salt spray	< 80 h (at 5 µm NiP as base layer)
Conductivity	Yes
Hydrogen embrittlement	Low

Coating process

The workpieces are degreased in hot alkaline fluid and then immersed in the coating bath where the NiP layer is formed autocatalytically.

FR particles of typically 0.2–0.3 µm diameter are stirred up to remain floating in the fluid, so they add themselves to the growing NiP matrix and form a layer with excellent sliding properties.

After the layer formation, a thermal treatment can be applied for specific applications. This thermal impact leaves the FR undestroyed and unmodified.

Traditionally, the friction reducer has been PTFE. Due to PFAS regulations, PTFE is replaced by different polymeric substances with similar properties.

Hybrid Ni+Cr (NiCr)

Description

Hybrid Ni+Cr is a hard silver-coloured two-part layer of nickel and chromium. Hard chromium is strong and wear-resistant, but it has a limited anti-corrosion effect due to its microcracks structure. With the good adhesion of nickel to steel, and its tight structure, a first layer of nickel enhances the properties of a hard chromium layer, adding chemical and corrosion protection. The original mechanical properties such as hardness and wear resistance of the surfaces, remain unchanged. Light anti-corrosion requirements are met with 2–10 µm NiP, strict requirements may need 25–50 µm NiP.

Typical applications and current use

On plain bearings, the inner ring raceway is usually plated with hard chromium to increase the bearing life. In plain bearings under heavy static or alternating loads and also shock loads, where higher anti-corrosion properties are specified, Hybrid Ni+Cr is used. They are used in different applications:

- Automotive
- Railways
- Construction
- Agriculture
- Pumps and valves

Features and benefits

- High hardness and high wear resistance
- Friction reduction for sliding application
- Strong anti-corrosion properties
- Strong surface protection against environmental influences
- Resistance against abrasive dirt

Coating process

The complete coating consists of two separate coatings that are carried out subsequently in a chemical and an electroplating process onto the required surfaces.

The surface is first covered with a nickel layer, preferably electroless nickel (NiP), to improve the corrosion protection and give chemical resistance, and then a hard chromium layer that adds mechanical resistance.

Hybrid Ni+Cr

Property	Value
Layer thickness	10–30 µm
Layer hardness	800–1200 HV
Production temperature	< 85 °C
Layer temperature stability	< 400 °C
Possible diameter range	Max. 550 mm
Possible width range	Max. 270 mm
Possible weight range	Max. 200 kg
DIN EN ISO 9227 NSS salt spray	200–1000 h (depending on thickness)
Conductivity	Yes
Hydrogen embrittlement	De-embrittlement may be recommendable

Copper (Cu)

Description

Copper is a soft, reddish gold-coloured layer, typically used as a bonding agent and sublayer under various coating systems. Since a copper layer cannot carry a high load, it can only be used as a bonding layer underneath an equally soft layer, such as silver.

Copper has good emergency operating properties and can be compared to a dry lubricant. It will wear under a sliding load, but it will slow down welding and lower the risk of severe damage. Its levelling ability, together with geometry adaption under load and wear, can lead to smoothened surfaces with good sliding properties.

Typical applications and current use

Copper plating is used as steel cage coating, or in rare cases, ring or roller coating, especially when lubrication problems between rolling elements and cages are expected and risk of seizure needs to be reduced. There are other coating possibilities competing with copper and the number of applications demanding copper is limited. A silver layer is often used on top of the copper layer as a main functional layer.

Features and benefits

- Soft metal layer with emergency running properties
- As a sublayer, adhesion promoter for other layers (mainly with cyanidic electrolyte)
- Tension equalization between substrate and harder top layers
- Slight reduction of corrosion, and reduction of tribo-oxidation
- Excellent electrical and thermal conductivity
- Surface levelling (mainly with acidic electrolyte)

Coating process

The workpieces are degreased in hot alkaline fluid, possibly etched, and then immersed in an acidic or alkaline electrolyte for the galvanic coating. Depending on the electrolyte, layer properties vary. Alkaline cyanidic electrolyte is used to achieve better bonding properties, while acidic electrolyte is used for surface levelling tasks. The process ends with cleaning and post-treatment or preservation. Unprotected copper will easily react and suffer from discolouration, which is why chemical colouration, passivation, painting or a top layer often is added after the copper plating.

Copper

Property	Value
Layer thickness	2–15 µm
Layer temperature stability	200 °C (but chemically reactive)
Layer hardness	35–200 HV (typically 150 HV)
Friction	Relatively high, but soft metal acts as emergency lubricant
Production temperature	< 80 °C
Conductivity	Excellent
Hydrogen embrittlement	De-embrittlement may be recommendable (process dependent, low at alkaline variant)

Silver (Ag)

Description

Silver is usually used with a copper sublayer to increase adhesion and to smoothen the substrate surface. Chemical resistance against many acids and alkalines and soft metal properties makes silver a potential choice for dry lubrication and chemical shielding. Gold plating delivers even better chemical protection but is often too expensive, while silver offers significant resistance at a moderate price.

On steel substrates, a silver layer is typically plated with a copper bonding sublayer, which gives good adhesion. On brass substrates, however, no sublayer is required. As it is a soft layer, silver will wear under a sliding load, but it will slow down welding and lower the risk of severe damage that can be caused by lubrication starvation.

Typical applications and current use

Its use is mainly limited to the plating of steel cages and, in rare cases, also rings for certain demanding applications. Such applications can be used when lubrication problems between rollers and cage are to be expected or additional safety is desired, for instance in aerospace applications.
In some cases, hybrid bearings with silver-coated rings and ceramic rollers can be considered. In high temperature applications, vacuum applications and in the food industry, dry lubrication with silver is beneficial to increase operational safety.

Features and benefits

- Soft metal layer with emergency running properties
- Levelling or smoothening surfaces
- Dry lubrication properties, applicable at high temperatures and when in a vacuum
- Excellent electrical conductivity
- Good corrosion protection with undamaged layers, mainly against chemicals (moderate alkaline and acidic)

Silver

Property	Value
Layer thickness	2–6 µm
Layer temperature stability	< 850 °C
Layer hardness	40-120 HV (alloyed up to 200 HV)
Friction	High (no tolerance)
Production temperature	< 80 °C
Conductivity	Excellent
Hydrogen embrittlement	De-embrittlement may be recommendable (process dependent, low at alkaline variant)

Coating process

The workpieces are degreased in hot alkaline fluid, possibly etched and then immersed in electrolytes for the galvanic coating of copper, followed by silver. The process ends with cleaning and preservation.

To further enhance hardness, silver can be alloyed with copper. The layer can then reach 160–200 HV but its dry lubrication properties are reduced. Besides galvanic coating, there are also other layer forming methods such as vapour condensation.

Tin (Sn)

Description

Tin is a dull grey silver or shiny silver coloured layer. Tin can exist in different forms (alpha, beta, gamma). It disintegrates below 13 °C, gets brittle at 160 °C, and melts at 232 °C. This significantly limits the applicable temperature range.

Tin layers are used in the same way as copper or silver. Being a soft metal in the given intermediate temperature range, tin layers have temporary dry lubrication properties, are able to fill pores and smoothen the surface, and deliver some anti-corrosion properties as long as the layer is not damaged.

Typical applications and current use

Tin coatings are rather unusual. When they are used, it is mainly for plating of steel cages for certain applications, especially when lubrication problems between rolling elements and the cage are expected. In a few cases, tin layers are also applied as low-level anticorrosion layers, for example in composite plain bearings.

Features and benefits

- Soft metal layer with emergency running properties, dry lubrication function
- Excellent electrical conductivity
- Surface levelling or smoothening
- Good corrosion protection if the layer is undamaged, mainly at thicker layers
- Good in contact with aluminium

Coating process

The workpieces are degreased in hot alkaline fluid, possibly etched, and then immersed in an acidic or alkaline electrolyte for galvanic coating. The process ends with cleaning and preservation.

With the galvanic process, the tin layer thickness is typically at or below 3 µm. Thicker layers up to 30 µm can be achieved by other immersion processes, like hot dip tinning.

Tin

Property	Value
Layer thickness	2-30 µm (galvanic < 3 µm)
Layer temperature stability ą-tin (inadequate) ß-tin (applicable) ẙ-tin (inadequate)	 < 13.2 °C 13.2–162 °C > 162 °C
Layer hardness	20–30 HV
Friction	Relatively high, but soft metal acts as emergency lubricant
Production temperature	< 80 °C
Conductivity	Yes
Hydrogen embrittlement	De-embrittlement may be recommendable (process dependent)

NoWear®

Description

NoWear® is a metal-containing amorphous carbon-based coating used to increase rolling bearing performance. It has a bonding sublayer to enhance adhesion and a top layer to support initial running-in. High hardness makes the surface insensitive to wear and impact from abrasive contaminations.

Typical applications and current use

Designed to overcome several common causes of bearing failures – light loads, high speeds, high vibration levels, inadequate lubrication – typical applications where NoWear® coated rolling bearings are used include:

- Papers machines
- Wind energy (rollers)
- Hydraulic pumps and compressors
- Marine and offshore applications
- Mining and mineral processing machines
- Industrial fans
- Racing

Features and benefits

- High wear resistance
- High-speed capabilities
- High load carrying capacity at low speed
- Insensitive to contamination
- Surface protection at poor lubrication
- Delayed start of lubrication starvation
- Reduced need for extreme pressure and anti-wear additives in the lubricant
- Reduction of smearing at low load condition
- Reduced risk of false brinelling damage
- Protection against adhesive wear
- Low friction, even in dry conditions
- Minimal impact on electrical conductivity

Coating process

After intensive cleaning, the workpieces are placed in a vacuum chamber, where several layers are applied to the bearing components' surfaces with a physical vapour deposition process.

Bearing surfaces coated with NoWear® retain the toughness of the underlying bearing steel material while adopting the hardness, improved friction properties and wear resistance of the coating.

NoWear®

Property	Value
Layer thickness	1–4 µm
Layer hardness	1200 HV
Layer composition	Metal-containing DLC (with bonding sublayer and running-in layer)
Layer temperature stability	300 °C
Friction coefficient	0.15 (dry)
Possible ring diameter range	Max. 700 mm
Possible roller diameter range	Max. 170 mm
Possible ball diameter range	Max. 50 mm
Resistance against	Contamination, poor lubrication

INSOCOAT – electrical insulation

SKF competence

INSOCOAT is an electrical insulating layer. Bearing components with complex geometries can be coated and in a rolling bearing usually the non-functional surfaces of either the outer ring or the inner ring are coated.

Typical applications and current use

SKF produces tapered rolling bearings, cylindrical roller bearings, spherical roller bearings, CARB toroidal bearings and ball bearings with INSOCOAT, with deep groove ball bearings and cylindrical roller bearings as the most common bearing types. The most common sizes are small to medium size. The main use is industrial applications where high insulation performance is required:

- Railway traction motors
- Generators
- Electric motors

Features and benefits

The main advantages of INSOCOAT are related to electricity resistance.

- Insulation against electrical current
- Prevents the functional surfaces from electrical erosions
- Provides corrosion protection for the directly coated surfaces

Coating process

The pre-treatment process steps include degreasing, drying and sand blasting. With plasma coating, the layer is formed through atmospheric plasma spray (APS) with molten aluminium oxide (Al_2O_3) particles. Finally, the workpieces go through sealing, followed by curing. An additional finish grinding step helps provide correct bearing dimensions.

INSOCOAT – electrical insulation

Property	Value
Layer thickness	100–300 µm
Layer operating temperature	< 150 °C Nominal operating conditions temperature (t) ≤ 40 °C relative humidity (rH) ≤ 60%
Layer breakdown voltage	≥ 3 000 V DC
Layer electrical resistance	≥ 200 MΩ DC
Possible diameter range	65–1 200 mm
Layer composition	Al_2O_3, sealant
Hydrogen embrittlement	No
Resistance against	Electricity, voltage strike, humidity

High friction coating (HFC)

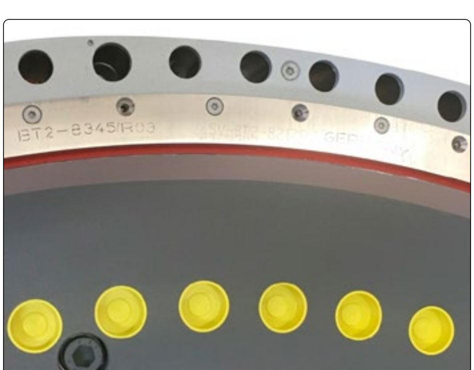
Description

HFC is a one-layer paint, about 35 µm thick. It is applied with roller or spray to ground precision steel surfaces. Only surfaces that do not come in contact with the raceways can be coated. The paint consists of humidity-curing polyurethane as a bonding matrix with zinc as anti-creep and load carrying additive and titanium diboride as friction particles.

Typical applications and current use

High friction coatings are usually found between inner rings and on the outside faces of Nautilus large size bearings (tapered roller bearings). The HFC paint layer increases the friction coefficient between the steel surfaces and avoids unintended movements between inner rings or between the bearing and its surrounding structures. An ideal combination would be both surfaces having the same hardness, but even the combination of hardened steel against synthetic material works. Only one of the two functional surfaces is coated with HFC.

This coating is most common in the main shaft bearings of wind turbines. The wind industry was also the main driver of the development of HFC.



Features and benefits

- Suitable for large sizes e.g. 4.0 m
- Suitable for many geometries
- No need for workpiece dependent tools
- Dependable and high friction value
- Resistance to vibrations and microslip
- Resistance to oil and many chemicals
- Corrosion protection for the joint surfaces
- Only one side needs to be coated
- Indicator function protocols correct mounting pressure
- No prior sand blasting necessary, adheres to fine ground surfaces
- Not electrically insulating

Coating process

The surfaces need to be flat precision machined as the paint has a limited possibility of compensating for deep scratches or parallelism errors and the friction particles need to intrude into both surfaces. An advantage for bearing rings is that no sandblasting is carried out prior to painting.

First, the surface is cleaned to the highest surface energy with solvents and then the HFC is applied to the surface. Special properties and indicators included in the paint make it possible to keep the layer thickness within tight tolerances. The one-component paint then hardens through a chemical reaction triggered by air humidity. After hardening, the paint is mechanically and chemically stable with high adhesion. In addition to thickness and drying indicators, the paint also includes a pressure indicator. After disassembly, it can easily be seen if the required pressure has been applied to the surfaces.

High friction coating

Property	Value
Surface roughness before coating	Ra 0.4–1.6 µm ground / fine machined (3.5 µm hard turned)
Specified surface energy before coating	> 72 mN/m
Dry film thickness (matrix)	35 (+10 / −5) µm
Compressibility	5 µm (100 MPa) 7 µm (300 MPa)
Wet film thickness (matrix)	Dry film thickness + 40 %
Particle size as top peak thickness	~ 100 µm
Particle hardness	Knoop HK0.1: 2 600 N/mm² Mohs 9.5
Recommended surface pressure	100 N/mm² (MPa)
Possible surface pressure range	50–250 N/mm² (MPa)
Tested up to surface pressure	500 N/mm² (MPa)
Guaranteed friction coefficient	> 0.3 (under defined circumstances)
Friction coefficient test results (dry / oiled / greased + against steel / zinc / resin)	0.30–0.50
Period of further initial friction increase (training improvement) under oscillation	< 72 000 cycles
Oscillation and vibration tests	Up to 5 Mio. cycles
10 µm sliding oscillation without friction drop (500 N/mm²)	> 72 000 cycles
2 µm sliding oscillation without friction drop (500 N/mm²)	> 1.4 Mio. cycles
Adhesion to ground surface, standard formula	2–5 N/mm² (MPa)
Adhesion to ground surface, additives formula	5–10 N/mm² (MPa)

C3H, C5MH anti-corrosion paint

Description

SKF anti-corrosion paint systems consist of 2–7 layers in the range of 80–450 µm thickness, applied with roller or spray on fine turned or ground steel surfaces. Only surfaces that do not come in contact with the raceways can be coated.

Typical applications and current use

SKF anti-corrosion paint systems are usually found on the outer ring surfaces of SKF Nautilus large size bearings (tapered roller bearings). The paint systems raise the anticorrosion properties of the bearings to C3H (medium) and C5MH (extremely high) levels.

Anti-corrosion paint coatings are most common in the main shaft bearings of wind turbines in offshore or near-offshore applications. The wind industry was also the main driver of the development of anti-corrosion paint coatings.

Features and benefits

- Suitable for sizes up to or above 4.0 m
- Suitable for many geometries
- No need for workpiece dependent tools
- Dependable and high adhesion even on ground surfaces
- Resistance to oil and many chemicals
- Resistance to UV radiation
- Good mechanical resistance, for example during handling
- High corrosion protection
- Possible to repair, also at site and with brush
- No prior sand blasting required thus no particle contamination

C3H, C5MH – anti-corrosion paint

Property	Value
Thickness: C3H C5MH	 80 µm 450 µm
Layer temperature stability	< 150 °C
Possible diameter range	Suitable for large sizes e.g. 4.0 m
Deposition method	Roller or spray painting
Resistance against	Oils, greases and a wide range of chemicals
Function under	Humidity, sun and ultraviolet radiation
Corrosion resistance according to DIN EN ISO 12944	C3H; C5MH
Conductivity	Low
Hydrogen embrittlement	No

Coating process

No sandblasting is carried out prior to painting so there is no risk of hard particles remaining in the bearing and the geometry does not deteriorate.

First, the surface is cleaned to high surface energy with solvents and then the paint is manually rolled or sprayed on the surface. The layers are polyurthane-based with humidity curing, zinc-filled or other active or passive particles added. Special properties and indicators included in the paint make it possible to keep the layer thickness within tight tolerances.

UV cure paint

Description

UV cure paint is translucent and will stay so even if it is coloured according to requirements. Most UV cure paint systems are based on acrylated polyester, polyether, polyurethane, or epoxy compounds. Since UV cure paint layers need to let UV light penetrate, the possible layer thickness and composition are limited, resulting in a medium anti-corrosion level at best.

UV cure paint does not dry from time-consuming evaporation of solvents or water but hardens instantly when ultraviolet (UV) light with adequate wavelength and energy is applied. The fast-curing method can fit the cycle time of a line production.

Typical applications and current use

The typical use of UV cure paint is when a paint coating needs to be applied in-line in a production channel, matching the machining cycle times. Using a UV cure paint is a good solution when there is no time for conventional curing and drying. One example is the production of hub bearing units.

Features and benefits

- Fast in-line process with instant curing
- Parts can be handled directly after coating
- No volatile organic compounds (VOC)
- High flash point

Coating process

UV cure paint is sprayed on to clean workpieces. Then energy generated by UV lamp systems activates the coating to achieve the cure. In the curing process, photo initiators are cracked by high-energy radiation with adequate wavelength and thus produce reactive particles. The reactive particles initiate radical or cationic polymerization, changing the structure from low-molecular to high-molecular in seconds. Organic or inorganic pigments can be added to a UV paint, as long as radiation can pass through. Moreover, an increased temperature makes molecules more movable, so a higher degree of polymerization and final hardness can be reached before the reaction ends in frozen state.

UV cure paint

Property	Value
Layer thickness	15–25 (40) µm
Production temperature	40 °C
Resistant against	Corrosion, environmental influences
DIN EN ISO 9227 NSS salt spray	96 h (variants up to 350 h)
Conductivity	No
Hydrogen embrittlement	No

Diamond-like carbon (DLC) and other vacuum deposited layers

Description

Coatings of diamond-like carbon (DLC) are carbon-based layers with compositions containing a mixture of graphite and diamond structures. They can either include or exclude hydrogen. Their composition influences the properties of the coatings. In general, they have high hardness, and low friction. The highest hardness can be achieved by a maximum amount of diamond structure, but this weakens the dry lubrication effects. The coating mixture can be adjusted according to the application.

A unique feature of DLC coatings is their running-in characteristics. A small portion of the coating surface transforms into a low-friction graphitic contact zone that is transferred onto the counter surface. This mechanism protects the counter steel surfaces that otherwise would be damaged by the harder coating.

CrN and CrCN coatings are examples of very hard layers with excellent adhesion, chemical and mechanical resistance, low friction and anti-wear properties. CrN is also used as bonding sub-layer.

At SKF, we can produce and deliver more vacuum deposited layers than described here. Contact SKF for more information.

Diamond-like carbon and other vacuum deposited layers

Property	Value (DLC)	Value Range (others)
Layer thickness	1–3 µm	1–10 µm
Layer hardness	1 500- 2800 HV	1 000–3 000 HV
Layer composition	Amorphous hard carbon (with bonding sub-layer)	
Layer temperature stability	300 °C	150–300 °C
Friction coefficient	0.1–0.2 (dry)	0.05–0.3 (dry)
Possible ring diameter range	Max. 700 mm	Max. 800 mm
Possible roller diameter range	Max. 170 mm	
Possible ball diameter range	Max. 50 mm	
Resistance against	Contamination, poor lubrication	

Typical applications and current use

DLC coatings are designed for high wear conditions and poor lubrication situations. Due to their low friction coefficient, they are ideal for sliding parts in engine components, compressors, linear drives, cages, bearing shafts and bushes. Typical applications include aerospace, automotive and racing.

CrN and CrCN coatings provide high hardness, friction reduction, strong protection against abrasive wear, protection during poor lubrication situations and against oil contamination. Typical market applications are engine parts, especially CrN is used as bonding promoter underneath other vacuum deposited layers.

Features and benefits

- High sliding and adhesive wear resistance
- High load carrying capacity
- Excellent abrasion protection
- Surface protection at poor lubrication
- Low friction
- Insensitive to contamination
- Reduced need of extreme pressure (EP) and anti-wear (AW) additives in the lubricant
- Reduction of smearing at low load condition

Coating process

After intensive cleaning the workpieces are placed in a vacuum chamber, where several layers are applied on the bearing components' surfaces with a physical vapor deposition (PVD) or plasma assisted chemical vapor deposition (PACVD) process.

PVD and PACVD coated bearing surfaces retain the toughness of the underlying bearing steel material while adopting the hardness, improved friction properties and wear-resistance of the coating.

Tungsten/molybdenum disulfide (WS_2 / MoS_2)

Description

Molybdenum disulfide (MoS_2) or tungsten disulfide (WS_2) are powders with dry lubrication and low friction properties that are mechanically adhered and clamped onto steel surfaces or onto other coatings. A surface coated with MoS_2 or WS_2 powder receives a silver metal colour, although the powder is black.

Typical applications and current use

SKF applies MoS_2 and WS_2 containing pastes to upgrade manganese phosphate (MnPh) layers by filling their micropores. It supports MnPh layers under harsh operating conditions such as poor lubrication and water inclusion, as in metal rolling applications.

Features and benefits

- Dry lubrication properties
- Low friction
- Emergency lubrication function
- Sealant property for other porous layers
- Water-repellent property (hydrophobic)
- Safe handling and storage of the raw paint materials

Coating process

MoS_2 and WS_2 can be supplied as paste or powder. It is rubbed onto the surface with a soft carrier material, with a cloth or a brush, alternatively by vibro-finishing or tumbling. For applications where oil may wash the powders off, the MoS_2 and WS_2 coating can be firmly anchored with a high-pressure spray method viakinetic energy or adhered with a paint-like binder.

Tungsten/molybdenum disulfide

Property	Value
Layer thickness	0.5–5 µm
Layer temperature stability	< 300 °C
Layer hardness	< 300 HV
Friction coefficient	< 0.05 (dry, PTFE vs. steel)
Possible range	No limits
Dry lubrication	Yes (also as emergency lubrication)
Water repellency	Yes
Hydrogen embrittlement	No

Customization and innovation

The coatings shown in this guidebook do not represent the complete SKF coatings offer. Additional coatings are available, for example related to chemical challenges, to hydrogen barrier functions, to food safety, and to highly environmentally friendly approaches, so please contact us to discuss your coating requirements if they are not fully met with the coatings presented in this guidebook.

Some coatings are not in the SKF portfolio but can be produced and delivered on explicit customer request. SKF is always interested in receiving a convincing business case that can justify the consideration of a specifically tailored inventive coating solution.

SKF is experienced in design and implementation of innovative coatings beyond the known market range and even has coatings still in development that might not yet meet the technical readiness level for general promotion and use.

The size ranges given in this document are mostly related to current production and not technological limits. Size increase may be possible at short notice.

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