

Surface Technology

Coatings for automotive and industrial applications

Technical Product Information

Foreword

Key technologies in industrial production

Surface technology is one of the most important key technologies worldwide in industrial production. For more than a hundred years, coatings have been used to give components greater durability and increase their efficiency. The demands on surface technology are constantly changing.

While there continues to be a high demand for mechanical components with ever-increasing requirements for corrosion protection, wear protection and reduced friction, the energy transition and shift toward sustainable mobility transition now call for completely new coating solutions for the associated applications. These include coatings for electrical and thermal conductivity, electromagnetic compatibility, energy conversion and storage, and sensors.

The Schaeffler modular coating tool box presented in this publication takes these developments into account. Here you will find all validated Schaeffler coating systems, complete with the associated properties and application examples, and can see first-hand how Schaeffler surface technology contributes to the cost-effectiveness and sustainability of the entire Schaeffler product range.

Further information

- e-mail: surface.technology@schaeffler.com
- telephone: +49 (0)9132 82-85999

Should you require any assistance in relation to surface technology, please do not hesitate to contact us. Our team of experts is on-hand with professional advice to assist you in selecting a suitable coating system through to volume production, to examine return parts, and to answer any questions you may have.

Contents

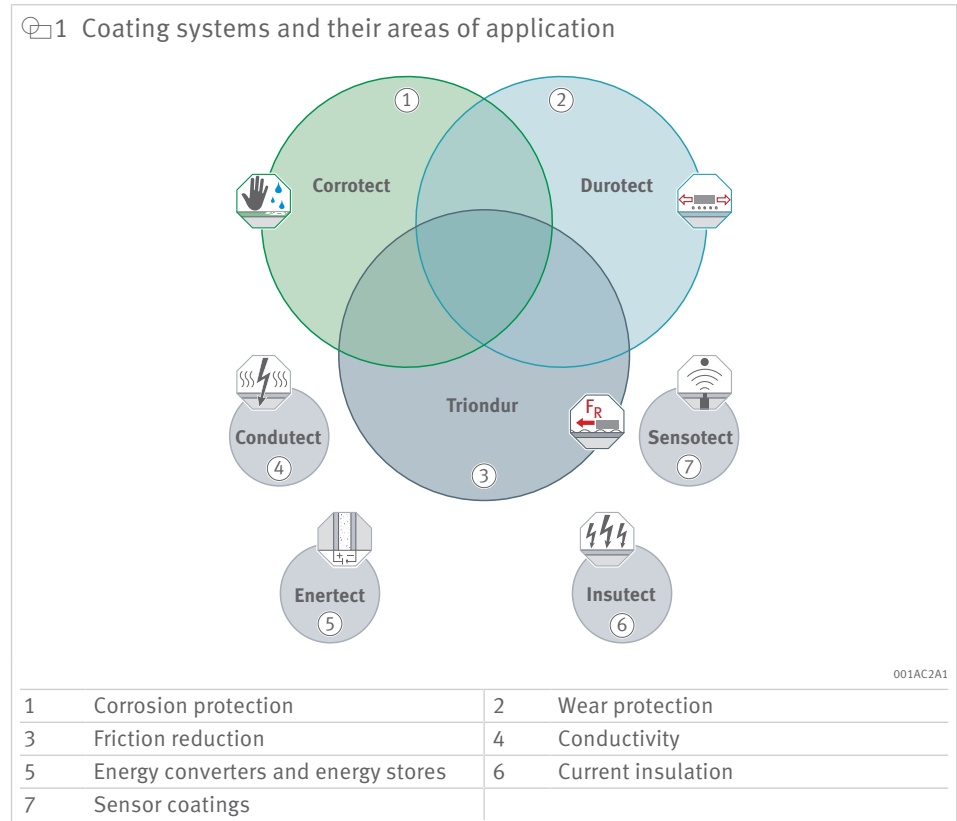
1	Technical principles.....	6
1.1	Modular coating tool box	6
1.1.1	Corrotect	6
1.1.2	Durotect	6
1.1.3	Triondur	6
1.1.4	Conductect	7
1.1.5	Enertect	7
1.1.6	Insutect.....	7
1.1.7	Sensotect.....	7
1.2	Coating systems and their areas of application	8
1.3	Preselection of coatings	10
2	Corrosion protection	15
2.1	Corrotect coating systems	15
2.2	Coating methods	16
2.3	Coating variants.....	18
2.3.1	Corrotect A*, Corrotect N*	18
2.3.2	Corrotect ZI	20
2.3.3	Corrotect ZN	22
2.3.4	Corrotect ZK	24
2.3.5	Corrotect ZF, Corrotect ZF(rt)	26
2.3.6	Corrotect P	28
2.3.7	Corrotect H, Corrotect HP	30
3	Wear protection and friction reduction	32
3.1	Durotect coating systems	32
3.2	Coating methods	33
3.3	Coating variants.....	34
3.3.1	Durotect B	34
3.3.2	Durotect Z	36
3.3.3	Durotect M	38
3.3.4	Durotect CK	40
3.3.5	Durotect CM, Durotect CMT	42
3.3.6	Durotect NP	44
3.3.7	Durotect C	46
3.3.8	Durotect S	48
3.3.9	Durotect H	50
3.3.10	Durotect HT	51
3.3.11	Durotect HA	52
3.3.12	Durotect P	54
4	Coating systems for surfaces subjected to high tribomechanical stresses	56
4.1	Triondur coating systems	56
4.2	Coating methods	57
4.3	Coating variants.....	59
4.3.1	Triondur C	59
4.3.2	Triondur C+.....	61
4.3.3	Triondur CX+.....	62
4.3.4	Triondur CH	64

4.3.5	Triondur CN	65
4.3.6	Triondur TN.....	66
4.3.7	Triondur MN	67
5	Electrically conductive coatings	68
5.1	Conductect coating systems	68
5.2	Coating methods	68
5.3	Coating variants.....	70
5.3.1	Conductect ES.....	70
5.3.2	Conductect EG	71
5.3.3	Conductect EN	72
5.3.4	Conductect ET.....	73
5.3.5	Conductect EC.....	74
6	Coating systems for the conversion and storage of energy	75
6.1	Enerect coating systems	75
6.2	Coating methods	75
6.3	Coating variants.....	77
6.3.1	Enerect PI.....	77
6.3.2	Enerect PI+	78
6.3.3	Enerect PC+.....	79
7	Current insulation.....	80
7.1	Insutect coating system	80
7.2	Coating methods	80
7.3	Coating variants.....	81
7.3.1	Insutect A.....	81
8	Sensor technology, measurement of force and torque	83
8.1	Sensotect coating system	83
8.2	Coating variants.....	84
8.2.1	Sensotect.....	84

1 Technical principles

1.1 Modular coating tool box

The following coating systems are currently available.



1.1.1 Corrotect

Corrotect covers all coating systems that are used primarily to give protection against corrosion (film corrosion and base metal corrosion). Depending on the coating system, they are applied by means of electrochemical methods (electroplating), as a paint, or by thermal spraying.

1.1.2 Durotect

Durotect coating systems are used primarily in applications that require protection against wear, reduction in friction, or both. Depending on the coating system, they are applied by means of chemical or electrochemical methods, as a paint, or by thermal spraying.

1.1.3 Triondur

Triondur coating systems offer the best combination of wear protection and friction reduction for components subjected to very high tribomechanical stress.

They are applied under vacuum by means of PVD or plasma-assisted CVD methods.

1.1.4 ConduTECT

ConduTECT coating systems are intended for electrical and thermal conductivity and EMC shielding. The shift toward e-mobility and the increasing need for intelligent systems with electromechanical components (e.g. sensory bearings, robotics) is leading to a focus on new components such as plug contacts and busbars at Schaeffler. Thermal conductivity and electromagnetic compatibility (EMC) are also becoming increasingly important due to the transformation of the product portfolio.

With the new ConduTECT coating family, Schaeffler is addressing this change and offering appropriate coatings solutions to improve both electrical and thermal conductivity under a wide range of conditions, and thus also enable EMC shielding for lightweight applications.

1.1.5 EnerTECT

By far the largest share of global greenhouse emissions produced to date stems from the use and conversion of fossil fuels. The transformation of the energy market as part of the energy transition toward a CO₂ neutral supply based on renewable energy resources is key to achieving climate protection goals.

Courtesy of the newly developed EnerTECT coating series, Schaeffler has succeeded in elevating the use of electrolyzers and fuel cell technology to a whole new level in terms of efficiency, longevity, and costs. Thanks to their excellent performance, EnerTECT coatings can withstand harsh operating conditions, even on metallic components such as steel bipolar plates, demonstrating high electrochemical stability in parallel with high electrical conductivity and robust mechanical characteristics.

1.1.6 InsuTECT

InsuTECT covers coating systems that are used primarily to achieve insulation against current. They are applied by means of thermal spraying.

1.1.7 SensotECT

SensotECT is a sensory coating that facilitates expansion in the functions of components. This is of particular significance in conjunction with the subjects of Industry 4.0 and digitalization.

This coating system is used for the continuous measurement of force and torque on 2-dimensional and 3-dimensional component geometries. The particular feature in this case is that the sensor technology can be applied by means of PVD technology and subsequent laser structuring directly to the component surface.

1.2 Coating systems and their areas of application

The use of specifically formulated coating systems improves the potential usage of components in the automotive and industrial sectors. Coating systems are therefore regarded as an independent design element.

Coating is a proven method for increasing the performance capability of the base material by functional expansion and thus providing components with additional characteristics for specific applications. For many years, Schaeffler has coated rolling bearings and precision components in order to improve corrosion protection as well as the tribological and electrical insulation characteristics.

Corroded bearing parts can lead to functional problems, lower efficiency, and premature failure of bearings. Appropriate coatings can be an alternative to expensive, corrosion-resistant bearing steels.

The quality of a rolling bearing is determined to a significant extent by its smooth running and wear resistance. These factors influence not only the basic function but also the requirement for energy and process materials. A low friction coefficient reduces not only energy consumption but also the requirement for lubricant. This is associated with less mechanical wear. In turn, this secures the function of the bearing for the long term and its operating life is extended.

For the improvement of tribological behavior, the Durotect and Triondur coating systems are suitable. Through selection of the correct coating, performance under poor lubrication conditions (lubricant starvation) can also be significantly improved in these cases.

In order to prevent rolling bearing damage as a result of current passage, the outside surfaces and end faces of the bearing rings can be provided with ceramic insulating coatings.

The following tables give a general overview of the performance strengths of coatings in relation to corrosion protection, wear protection, and friction reduction.



The actual performance is dependent on the specific application and may vary in some cases. In such cases, please contact Schaeffler.

1 Characteristics of coatings with corrosion protection as the principal function

Coating system	Principal function		
	Corrosion protection	Wear protection	Friction reduction
Corrotect ZK	+	--	--
Corrotect ZI	++	--	--
Corrotect ZN	+++	--	--
Corrotect ZF, Corrotect ZF(rt)	+++	--	--
Corrotect P	++	--	--
Corrotect H	++	--	--
Corrotect HP	+++	--	--

2 Characteristics of coatings with wear protection as the principal function

Coating system	Principal function		
	Corrosion protection	Wear protection	Friction reduction
Durotect NP	++	++	--
Durotect HA	+	+	--
Durotect CM, Durotect CMT	+	++	+
Durotect CK	+	+++	+
Durotect HT	--	++	--

3 Characteristics of coatings with friction reduction as the principal function

Coating system	Principal function		
	Corrosion protection	Wear protection	Friction reduction
Durotect B	-	+	+
Durotect M	-	+	+
Durotect Z	-	+	+
Durotect C	--	--	+
Durotect S	--	--	+
Durotect P	+	+	++
Triondur systems	--	+++	+++

- +++ high
- ++ medium
- + low
- short term (e.g. for transport with oiling)
- not ensured

1.3 Preselection of coatings

4 Corrotect coating systems free from Cr(VI), corrosion protection

Coating system	Composition	Principal function			Additional function	Main area of application
		Corrosion protection	Wear protection	Friction reduction		
Corrotect A*	Zinc-iron thin film	+	–	–	–	Belt drives Selector shafts Bearings Bearing components
Corrotect N*	Zinc-iron thin film	+	–	–	–	Belt drives Detent pins
Corrotect ZI	Zinc-iron	+	–	–	–	Belt drives Bearing components Screw with moderate corrosion protection requirements
Corrotect ZN	Zinc-nickel	+	–	–	–	Belt drives Bearing components Screw with high corrosion protection requirements
Corrotect ZK	Zinc	+	–	–	–	Simple corrosion protection applications
Corrotect ZF, Corrotect ZF(rt)	Zinc flakes	+	–	–	Adjustment of friction coefficient possible with topcoat	Chassis engineering Components Screws and safety components with high tensile strength
Corrotect P	Paint systems	+	–	–	Current-insulating according to coating variant	Housings Flanges Slewing rings Fasteners Main bearings
Corrotect H	Zinc or zinc-aluminum	+	–	–	–	Corrosion protection for inner rings and outer rings of large size bearings Slewing rings Main bearings Generator bearing
Corrotect HP	Zinc or zinc-aluminum with topcoat	+	–	–	–	Corrosion protection for inner rings and outer rings of large size bearings Slewing rings Main bearings Generator bearing

5 Corrotect coating systems containing Cr(VI), corrosion protection

Coating system	Composition	Principal function			Additional function	Main area of application
		Corrosion protection	Wear protection	Friction reduction		
Corrotect C	Zinc-iron thin film	+	–	–	–	Bearings Bearing components
Corrotect F	Zinc-iron thin film	+	–	–	–	Linear components Individual bearing components

 **Information on REACH**

With the End of Life Vehicles Directive (EU-Richtlinie 2000/53/EG), the use of hexavalent chromium compounds was regulated for the first time. In the automotive sector, the use of post-treatments containing Cr(VI) in coating methods, so-called yellow chromate passivation (Corrotect C) and black chromate passivation (Corrotect F) is not permissible.

In April 2013, hexavalent chromium compounds were included in Appendix XIV of the REACH directive by the European Chemicals Agency on account of their mutagenic and carcinogenic effects. The background to this directive is the improvement of the protection of human health and the environment against risks that may arise from the use of chemicals. The REACH directive is valid within the entire European Union (in addition to Liechtenstein, Iceland, and Norway). Switzerland has laws that are harmonized with REACH.

Without authorization approved by the ECHA, the use of hexavalent chromium compounds in the coating process is prohibited with effect from September 2017 for all sectors within the scope of REACH. As a result, this also affects the industrial sector.

At Schaeffler, all affected materials are being progressively changed over to post-treatments free from Cr(VI). For all new parts, the coating variants Corrotect C and Corrotect are therefore no longer recommended or used.

6 Durotect coating systems, wear protection, and friction reduction

Coating system	Composition	Principal function			Additional function	Main area of application
		Corrosion protection	Wear protection	Friction reduction		
Durotect B	Mixed iron oxide	-	-	+	Improved running-in behavior Reduced slippage damage Short-term corrosion protection Reduced failures as a result of WEC	Belt drives Selector shafts Bearings Bearing components
Durotect Z	Zinc phosphate	-	-	+	Short-term corrosion protection (e.g. for transport) Protection against fretting corrosion Suitable for sliding seats Bonding layer for paint, soaps, oils, vulcanization	Aerospace Bearings Bearing components
Durotect M	Manganese phosphate	-	-	+	Improved running-in behavior Short-term corrosion protection (e.g. for transport) Emergency running lubrication Retention layer for dry lubricants	Aerospace Linear guidance systems Bearing components
Durotect CK	Columnar thin dense chromium coating	-	+	-	Corrosion protection possible, depending on the application Slightly reduced friction Reduced fretting corrosion	Linear technology Aerospace Vibratory screen bearings Spindle bearings
Durotect CM, Durotect CMT	Microcracked thin dense chromium coating	-	+	-	Corrosion protection possible, depending on the application Slightly reduced friction	Needle roller bearings Bearing components Engine components
Durotect NP	Nickel-phosphorus	+	+	-	Friction reduction by means of PTFE additives	Drawn cups Guide ring segments
Durotect C	Copper	-	-	+	Emergency running lubrication Dissipation of frictional heat	Cages in bearings running at high speeds
Durotect S	Silver	-	-	+	Emergency running lubrication Dissipation of frictional heat	Aerospace Linear guidance systems Bearing components Cages in bearings running at high speeds
Durotect H	Chromium steel or manganese steel	-	+	-	-	For dimensional correction of rolling bearing rings
Durotect HT	Range of variants	-	+	-	Increase in adhesive friction (static or dynamic)	Synchronizer rings, inner rings, intermediate rings
Durotect HA	Hard anodizing (Al)	+	- +	-	Current insulation	Sliding sleeves Bearing cages Housing components
Durotect P	Polymer-based coating		-	+	Protection against fretting corrosion Current insulation	Bearing rings Guide sleeves Cages

7 Triondur coating systems, wear protection, and friction reduction in components subjected to high tribomechanical stresses

Coating system	Composition	Principal function			Additional function	Main area of application
		Corrosion protection	Wear protection	Friction reduction		
Triondur C	a-C:H:Me (metal-containing hydrogenated amorphous carbon coating)	–	+	+	Reduction in slippage damage	Bearing components Engine components
Triondur C+	a-C:H (hydrogenated amorphous carbon coating)	–	+	+	–	Engine components Bearing components
Triondur CX+	a-C:H:X (modified hydrogenated amorphous carbon coating)	–	+	+	–	Engine components Bearing components, nanostructured Ideal combination of friction reduction and wear protection
Triondur CH	ta-C (tetrahedral hydrogen-free amorphous carbon coating)	–	+	+	–	Engine components Friction reduction with appropriate lubricant Highest wear resistance of all coating systems
Triondur CN	Cr _x N (chromium nitride)	–	+	+	–	Valve train components
Triondur TN	TiN (titanium nitride)	–	+	+	–	Bearing components Rib surfaces
Triondur MN	CuMoN (nitridic hard material layer)	–	+	+	Increase in temperature resistance	Engine components Bearing components, nanostructured

8 Condulect coating systems, electrically conductive protective layers for current-carrying components

Coating system	Composition	Principal function			Additional function	Main area of application
		Corrosion protection	Wear protection	Friction reduction		
Condulect ES	Silver	+	–	–	–	Applications in the automotive engine compartment Control unit bonding
Condulect EG	Gold	+	–	–	–	Plug connections with high safety implications Applications involving a large number of mating cycles
Condulect EN	Nickel	+	+	–	–	With wear-resistant surface specification for areas subjected to corrosion
Condulect ET	Tin	+	–	–	–	If gold and silver are not required or prescribed Soldered connections or weld connections Applications involving a small number of mating cycles
Condulect EC	Copper	–	–	–	–	Intermediate layer or connecting layer, conduct paths

9 Enerect coating systems, energy converters, and energy stores

Coating system	Composition	Principal function			Additional function	Main area of application
		Corrosion protection	Wear protection	Friction reduction		
Enerect PI	Coating containing precious metal	+	+	–	–	Components for the conversion and storage of energy
Enerect PI+	Coating with reduced precious metal content	+	+	–	–	Components for the conversion and storage of energy
Enerect PC+	Coating free of precious metal	+	+	+	–	Components for the conversion and storage of energy

10 Insutect coating systems, current insulation

Coating system	Composition	Principal function	Additional function	Main area of application
Insutect A	Aluminum oxide	Current insulation	–	Rail vehicles Electric motors Generators

11 Sensotect coating systems, sensor technology

Coating system	Composition	Principal function	Additional function	Main area of application
Sensotect	Multi-layer system comprising insulation coating and strain-sensitive PVD coating	Measurement of force and torque	–	Rolling bearings Bottom bracket bearings Wheel bearings Shafts Bending beams

2 Corrosion protection

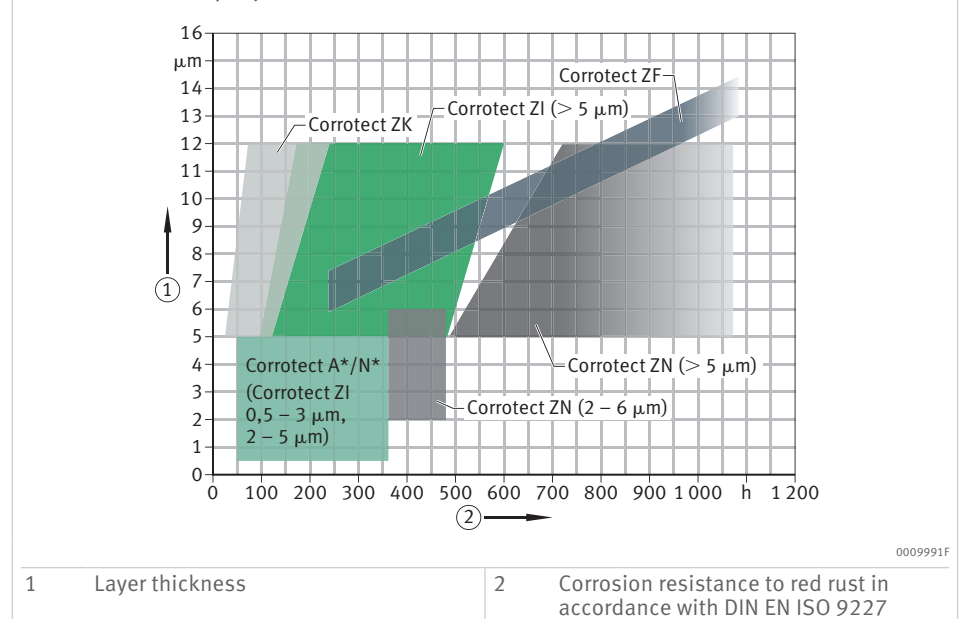
2.1 Corrotect coating systems

Rolling bearing components are normally manufactured from martensitic, bainitic, or case hardened rolling bearing steels such as 100Cr6. If standard rolling bearing steels come into contact with water or humidity, however, they can undergo corrosion, which can cause a permanent impairment of the intended function. Corrosion-resistant rolling bearing steels provide a remedy here but are expensive. The most economical variant for optimizing the characteristics under moderate corrosion conditions is therefore the combination of a standard rolling bearing steel with an appropriate coating. For particularly high corrosion loads, coatings resistant to seawater are available.

A wide selection of Corrotect coatings of differing performance capability ensures corrosion protection (for film and base metal corrosion) individually matched to the customer application. The anti-corrosion coatings from Schaeffler are explained in detail below and application examples are given.

Corrotect covers all coating systems that are used primarily to give protection against corrosion. The coating systems available for this purpose give protection in different ways. Depending on the coating system, the action is based on cathodic corrosion protection (as in the case of zinc alloys), anodic corrosion protection (as in the case of chemical nickel coatings) or a barrier effect (e.g. in paint systems).

② Comparison of Corrotect coating systems (cathodic corrosion protection) in the neutral salt spray test



In the neutral salt spray test (NSS test) in accordance with DIN EN ISO 9227, the components are exposed to a defined sodium chloride climate, in order to compare the corrosion protection performance of the coating systems.

2.2 Coating methods

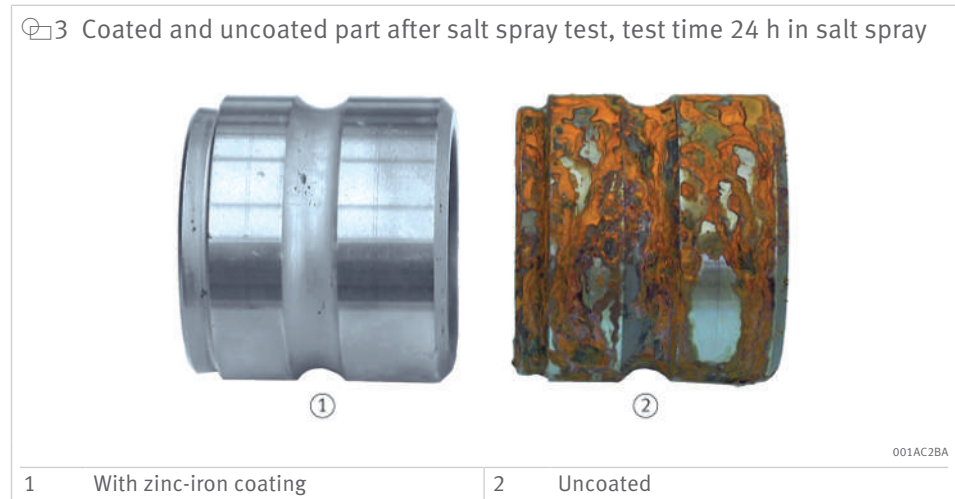
Depending on the coating system, the coating is either applied using an electrochemical (electroplating) process, e.g. for zinc alloys, or using the spraying or dipping method for paint systems.

Electroplated corrosion protection coatings

Zinc and zinc alloys have been used in industry for many years as an anti-corrosion coating. In rolling bearing applications, the soft layers on the overrolled area of the bearing raceway are worn away during operation, thus increasing the bearing clearance. Layer thicknesses of $> 5 \mu\text{m}$ are therefore not generally suitable in these fields. In the case of thin layer variants Corrotect A* and Corrotect N*, film thicknesses in the range of $0.5 \mu\text{m}$ to $5 \mu\text{m}$ are applied, making the use of these coatings possible with standard rolling bearings.

Due to their amphoteric character, zinc-based anti-corrosion coatings are suitable only under certain conditions or not at all for use in aggressive environments. In contact with acid or alkaline agents (pH values < 6 or pH values > 8), it must be expected that the coated surface will be attacked or accelerated film and base metal corrosion will occur.

- !** During the coating process, the component is located in an electrical circuit. As a result, an electrical field of varying intensity is formed over the whole component geometry, leading to increased film formation at edges (bone effect). Due to these physical effects, however, film deposition will be reduced or not present at all in holes, in undercuts, and on inner edges. Through the use of optimized coating fixtures specially matched to the component, these effects can in certain cases be reduced or eliminated.



Passivation and sealing of zinc coatings and zinc alloy coatings

In order to increase the corrosion protection effect, passivation is additionally carried out on zinc coatings and zinc alloy coatings. In this case, a conversion coating free from Cr(VI) is achieved by dipping the components in passivation solutions. This conversion coating protects the zinc-based coating against corrosion and thus extends the resistance of the complete system to white and red rust.

In special applications, additional sealing is possible. In this case, organic or inorganic substances are applied to the passivation as a cover layer. This gives a further increase in corrosion resistance.

Combination of different metal contact surfaces

The protective performance of coatings with cathodic corrosion protection is sharply reduced by contact with precious or semiprecious metals such as copper sealing rings as a result of the electrochemical potential difference generated. Contact between different metal surfaces should therefore be avoided wherever possible.

Transport and handling tasks

If there are only slight requirements for corrosion resistance, for example in connection with transport, storage, and handling tasks, economical zinc phosphating (Durotect Z) or black oxide coating (Durotect B) is possible, in each case with the application of oil. In this case, however, the expectations placed on the protection system must be compared with the possible system performance levels and carefully weighed up. In general, these simple protection systems only give acceptable corrosion protection levels if oil is applied to the parts at the same time.

Paint-based anti-corrosion coatings

In the case of large component dimensions or components with special requirements, the dipping of components in electrolytes for an electroplating process is often not possible. As an alternative, paints (Corrotect P) or a high-resistance, paint-based coating system (Corrotect ZF and Corrotect ZF(rt)) are therefore used for corrosion protection.

Other coatings for corrosion protection

In contact with highly corrosive media such as acids or alkalis, nickel-phosphorus coatings (NiP coatings) deposited by electroless methods have proved effective. However, as these call for greater layer thicknesses, a corresponding tolerance must be taken into account when designing the component.

Columnar thin dense chromium coating

As an anti-corrosion coating resistant to wear and overrolling, the columnar thin dense chromium coating Durotect CK can also be used.

2.3 Coating variants

2.3.1 Corrotect A*, Corrotect N*

Zinc-iron coating (layer thickness $\leq 5 \mu\text{m}$) with thick film passivation A* or nanoparticle-backed thick film passivation N*

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- protection against base metal corrosion (red rust formation)
- economical, cathodic corrosion protection
- thin film coating technology allows complete bearing coating without taking account of deviations and tolerance specifications

Common applications

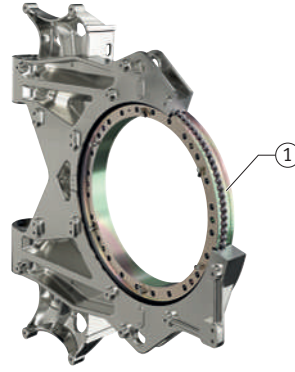
Various bearings, bearing components, and bearing adjacent parts with requirement for increased corrosion resistance:

- bearing inner rings, outer rings
- drawn cup needle roller bearings, and thin-walled components in large quantities, e.g. detent sleeves

12 Characteristics

Feature	Coating	
	Corrotect A*	Corrotect N*
Composition	Zinc-iron	
Post-treatment	Thick film passivation	Nanoparticle-backed thick film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 48 h and 360 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)	
Color	Silver, iridescent	Silver, slightly iridescent
Layer thickness	0.5 μm to 3 μm 2 μm to 5 μm	
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8	

4 Application example, swivel system



0009E14B

- 1 Four point contact bearing, inner ring coated with Corrotect A*

2.3.2 Corrotect ZI

Zinc-iron coating (layer thickness > 5 µm) with thick film passivation A* or nanoparticle-backed thick film passivation N*

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- protection against base metal corrosion (red rust formation)
- economical, cathodic corrosion protection


Common applications

Components with requirement for increased corrosion resistance, such as:

- adjacent bearing parts
- housings
- belt pulleys
- levers

13 Characteristics

Feature	Coating	
	Corrotect ZI A*	Corrotect ZI N*
Composition	Zinc-iron	
Post-treatment	Thick film passivation	Nanoparticle-backed thick film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 120 h and 600 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)	
Color	Silver, iridescent	Silver, slightly iridescent
Layer thickness	> 5 µm	
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8	

 Every application that involves contact with seals must be examined individually.

5 Belt drive decoupler



001ABD86

6 Application example, belt drive



000A09E8

2.3.3 Corrotect ZN

Zinc-nickel coating with thick film passivation A*

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- protection against base metal corrosion (red rust formation)
- high quality, cathodic corrosion protection
- best ratio between layer thickness and corrosion protection effect

Common applications

Components with requirement for very high corrosion resistance, such as:

- steering and detent bushes
- bearing pins
- mechanical levers
- large bearing rings with max. diameter of 1 m

14 Characteristics

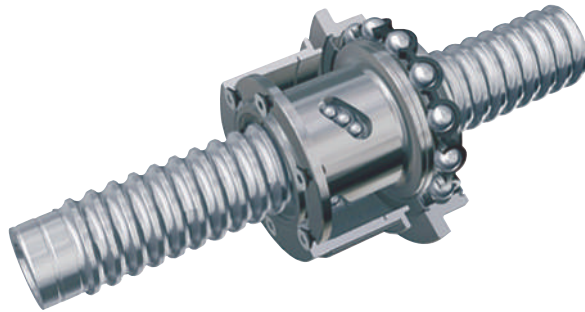
Feature	Coating
	Corrotect ZN A*
Composition	Zinc-nickel
Post-treatment	Thick film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 360 h and 720 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227) In combination with a performance-enhancing post-treatment, corrosion protection of more than 720 h against red rust may be possible.
Color	Silver-blue, in some cases with colored iridescence
Layer thickness	> 2 µm
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8

7 Outer ring from ball screw drive, coated with Corrotect ZN A*



0009E18C

8 Application example, ball screw drive



000B2DEF

2.3.4 Corrotect ZK

Electroplated zinc coating with thick film passivation A* or thin film passivation A or B

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- protection against base metal corrosion (red rust formation)

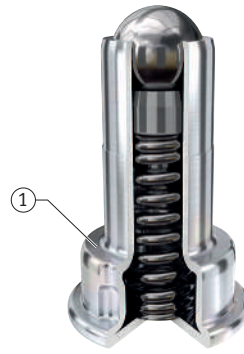
Common applications

Components with requirement for slight corrosion resistance:

- simple blanked and bent parts
- small mounting parts such as impact sleeves
- screws


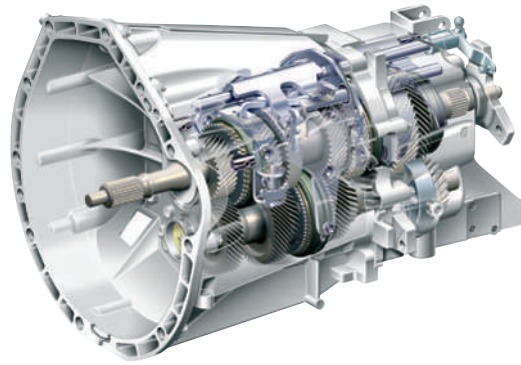
15 Characteristics

Feature	Coating		
	Corrotect ZK A*	Corrotect ZK A	Corrotect ZK B
Composition	Zinc		
Post-treatment	Thick film passivation	Thin film passivation	Thin film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 24 h and 240 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)		
Color	Silver, iridescent	Colorless, silver	Silver-blue
Layer thickness	> 5 µm		
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8		

 9 Selector rod detent pin from manual transmission

000A3F0D

1 Drawn cup coated with Corrotect ZK

 10 Application example, manual transmission

0009CA4C

2.3.5 Corrotect ZF, Corrotect ZF(rt)

Zinc flake coating

Coating process

- dipping, centrifugal, or spray method
- Corrotect ZF(rt) variant hardenable at room temperature

Advantages, benefits

- protection against base metal corrosion (red rust formation)
- partially cathodic corrosion protection similar to paint
- increased temperature resistance in comparison with normal anti-corrosion paints
- corrosion protection without subsequent heat treatment of high strength materials, no risk of hydrogen embrittlement due to coating process
- coating of mounted components possible

Common applications

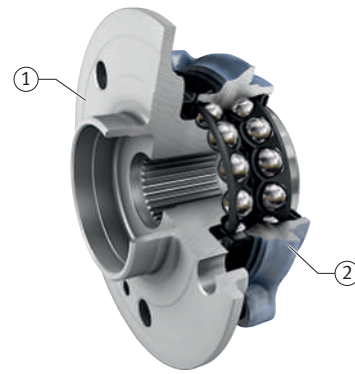
In automotive engineering:

- axle bearing components and wheel bearing components
- impulse rings and intermediate rings
- high strength screws (of or larger than thread M5)

16 Characteristics

Feature	Coating
	Corrotect ZF, Corrotect ZF(rt)
Composition	Zinc(-aluminum) flakes
Post-treatment	No passivation, topcoat in some cases
Corrosion resistance	Depending on the layer thickness, up to 1000 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)
Color	Silver-gray (topcoat can optionally be colored as required)
Layer thickness	> 5 µm

11 Wheel flange

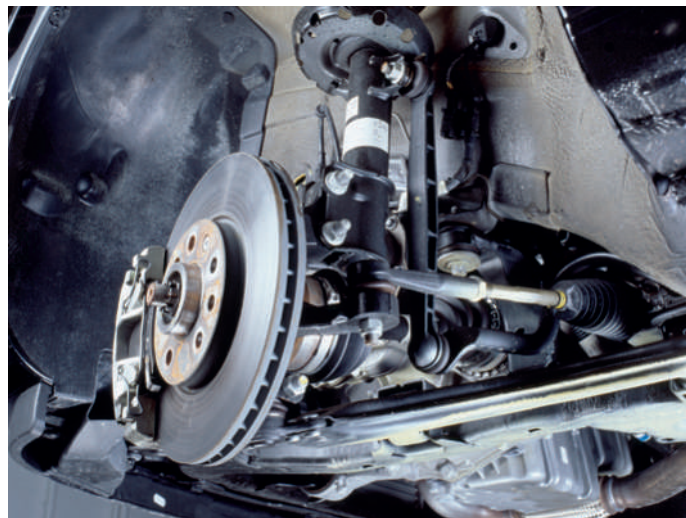


000A0271

1 Rim seat coated with Corrotect ZF or Corrotect ZF(rt)

2 Outer ring coated with Corrotect ZN

12 Application example, wheel suspension



000A39DB

2.3.6 Corrotect P

Polymer-based coating

Corrotect P includes various paint coating systems used for corrosion protection.

Coating process

- dipping method:
 - complete coating of individual components
- spraying method:
 - complete or partial coating
- curing temperature dependent on paint system, from room temperature to approx. +250 °C

Advantages, benefits

- protection against base metal corrosion (red rust formation)
- corrosion protection for various ambient conditions in accordance with DIN EN ISO 12944, corrosivity categories C1 to C5-M
- no white rust formation
- depending on coating variant, current insulation in low voltage range
- good chemical resistance
- color freely selectable

Common applications

Components with low to very high requirements for corrosion protection, such as:

- rotor main bearing arrangements in wind turbines
- active roll control (housing, torsion bar)
- pillow block bearings
- wheel bearings

17 Characteristics

Feature	Coating
	Corrotect P
Composition	Polymer-based
Post-treatment	No passivation
Corrosion resistance	Corrosion protection in accordance with DIN EN ISO 12944, corrosivity categories C1 to C5-M Depending on the layer thickness, up to 720 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)
Color	Freely selectable
Layer thickness	15 µm to 500 µm

13 Active roll control



000A0A82

1 Roll arms coated with Corrotect P

14 Application example, SAF pillow block housing



001ABCF4

2.3.7 Corrotect H, Corrotect HP

Thermally sprayed, metallic layers as corrosion protection with zinc or zinc-aluminum (optionally with topcoat)

Coating process

- thermal spraying (optionally topcoat by painting)

Advantages, benefits

- corrosion protection for various ambient conditions in accordance with DIN EN ISO 12944
- corrosivity categories C1 to C5-M, possible corrosion protection period 15 a (protection period class H)
- coating of geometrically difficult and large-dimension components

Common applications

Very high corrosion protection for the following areas:

- inner and outer rings for large size bearings
- slewing rings, main bearings, and generator bearings in wind energy applications

18 Characteristics

Feature	Coating	
	Corrotect H	Corrotect HP
Composition	Zinc coating or zinc-aluminum coating	
Post-treatment	None	Polymer-based topcoat (paint)
Corrosion resistance	> 15 a possible, in accordance with DIN EN ISO 12944	
Color	Metallic	Topcoat suitable for individual coloring
Layer thickness	50 µm to 400 µm	

15 Tapered roller bearing system for wind turbines, coated with Corrotect H on all outside surfaces



000A04AF

16 Application example, offshore wind turbine



000A39FF

3 Wear protection and friction reduction

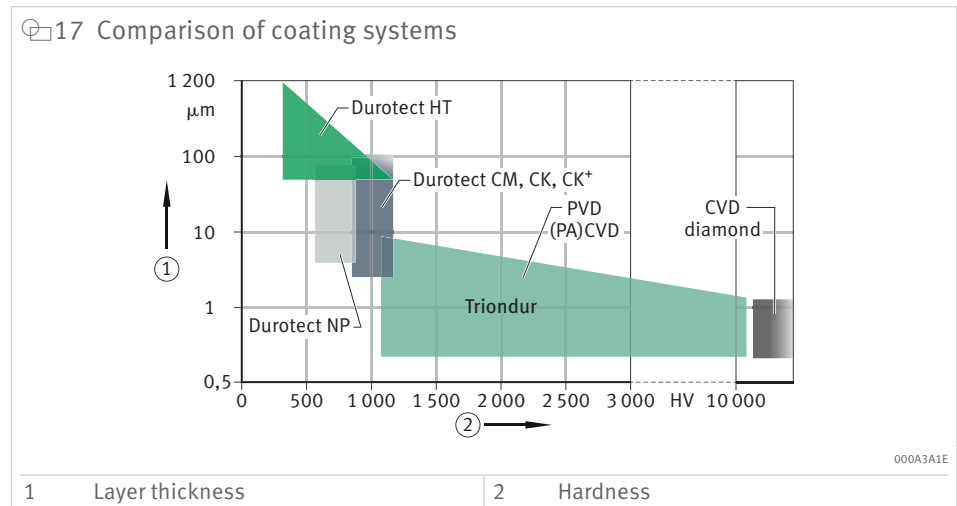
3.1 Durotect coating systems

The Schaeffler modular coating tool box provides various coatings for components under high tribological stress. These coatings are specifically matched to the respective application.

Furthermore, special Durotect coating systems offer additional functions such as emergency running lubrication, heat dissipation, protection against (tribo)chemical reactions (such as fretting corrosion) or short term corrosion protection (e.g. for transport).

Depending on the requirements of the component, the application process is carried out by means of chemical or electrochemical methods, as paint or by means of thermal spraying.

On the following pages, the coating systems are presented and application examples are given.



3.2 Coating methods

Abrasive and adhesive wear

High surface hardness is necessary for protection against abrasive wear. The contact partners can be protected here by particularly hard coatings.

Durotect coating systems such as Durotect CM, Durotect CMT, Durotect CK or Durotect NP can prevent abrasive wear, since they are harder than the base material.

Adhesive wear occurs principally in contact partners with similar bonding characteristics, such as steel on steel. In order to prevent this wear mechanism, the type of bond can be modified by the suitable coating of a contact partner.

A typical example of adhesive wear is slippage damage. This wear can be reduced by, for example, the targeted oxidation of the material surface, for example by means of black oxide coating.

In this respect, Schaeffler is setting new standards worldwide with the specially optimized black oxide coating method for the coating system Durotect B.

3.3 Coating variants

3.3.1 Durotect B

Mixed iron oxide coating with optimized surface structure

Coating process

- chemical conversion

Advantages, benefits

- no change to component geometry necessary
- geometrically stable coating even under bending and compressive stress on the component
- improved running-in behavior
- reduction in slippage damage
- increased robustness against WEC-induced failures
- improved resistance capability against surface-induced damage (surface initiated fatigue, SIF)
- improvement in friction characteristics in conditions of lubricant starvation

Common applications

- full complement cylindrical roller bearings
- ball bearings
- rolling elements and rings for bearings in wind turbines and railway drive bearings
- various components in transmission and belt drive systems

☐ 19 Characteristics

Feature	Coating
	Durotect B
Composition	Mixed iron oxide
Color	Dark brown to black
Layer thickness	≥ 0.5 μm

18 Single row cylindrical roller bearing, coated with Durotect B



0009CA55

19 Application example, wind turbine



0009F243

3.3.2 Durotect Z

Zinc phosphate coating

Coating process

- chemical conversion

Advantages, benefits

- temporary corrosion protection in oiled condition
- prevention of fretting corrosion (tribocorrosion) in bearing seats
- prevention of adhesive wear
- reduced damage as a result of standstill marks (false brinelling)

Common applications

- tapered roller bearings in rail vehicles
- large size bearings (predominantly in the paper industry)
- rolling bearing cages and drawn cups
- retention layer for lubricants such as soaps, oils, greases, or waxes
- primer for paints and zinc flake coating systems
- aid for cold forming (such as deep drawing)

20 Characteristics

Feature	Coating
	Durotect Z
Composition	Zinc phosphate
Corrosion resistance	≤ 24 h (with application of oil) according to salt spray test in accordance with DIN EN ISO 9227
Color	Light gray to dark gray
Structure	Fine crystalline structure
Layer thickness	1 µm to 10 µm
Temperature resistance	Up to +250 °C

20 Tapered roller bearing unit for application in heavy freight transport



000A0283

- 1 Inner ring, outer ring, and cage coated with Durotect Z

21 Application example, Rail



000A3D94

3.3.3 Durotect M

Manganese phosphate layer

Coating process

- chemical conversion

Advantages, benefits

- improvement in sliding and running-in behavior
- emergency running lubrication
- wear protection of cages
- prevention of adhesive wear
- reduced damage as a result of standstill marks (false brinelling)

Common applications

- sheet steel cages
- inner ring bores in crankshaft bearings
- primer for anti-friction paints and dry lubricants
- running-in aid for tappets

21 Characteristics

Feature	Coating
	Durotect M
Composition	Manganese phosphate
Corrosion resistance	≤ 24 h (with application of oil) according to salt spray test in accordance with DIN EN ISO 9227
Color	Dark gray to black
Structure	Fine crystalline structure
Layer thickness	1 µm to 10 µm
Temperature resistance	Up to +350 °C

④22 Spherical plain bearing GE80-DO-2RS, coating with Durotect M on inner and outer ring



000A086F

④23 Application example, straddle truck



000A090E

3.3.4 Durotect CK

Columnar thin dense chromium coating

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- high wear resistance especially at the axial contact running points or on fit surfaces where fretting corrosion is expected
- effective wear protection under mixed friction for small ball and roller bearings
- low friction coefficient under mixed friction
- unconstrained displacements in non-locating bearings enabled by reduced friction coefficients
- higher corrosion resistance compared with rolling bearing steel (salt spray test in accordance with DIN EN ISO 9227)

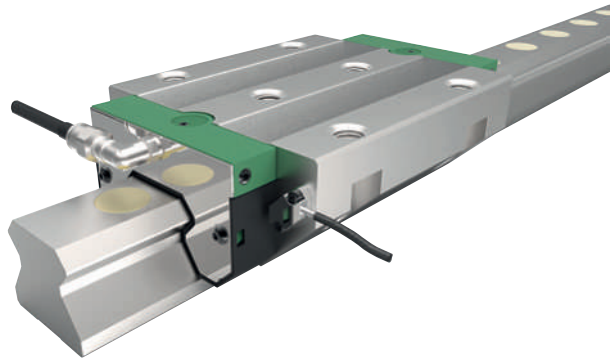
Common applications

- raceways in high precision bearings for aerospace applications
- outside surfaces of spindle bearings
- component coating of spherical roller bearings (rings, rolling elements) running in corrosive environments
- protection against fretting corrosion on inside surfaces
- inner and outer rings of ball bearings for swash plates in helicopters
- linear components in aggressive environments

22 Characteristics

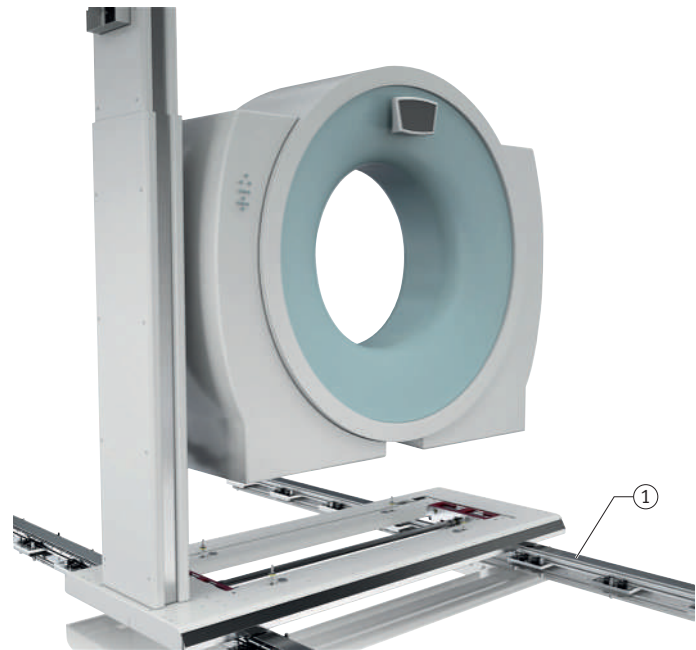
Feature	Coating
	Durotect CK
Composition	Hard chromium
Color	Gray (matt)
Structure	Pearly structure (columnar)
Layer thickness	1 µm to 4 µm
Hardness	900 HV to 1000 HV

24 Linear recirculating roller bearing and guideway assembly RUE, coated with Durotect CK on the outer surfaces



000A0A70

25 Application example, movable, rail-guided computer tomograph



000A0A66

1 Linear system coated with Durotect CK

3.3.5 Durotect CM, Durotect CMT

Microcracked hard chromium coating

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- improved friction and wear behavior under lubricant starvation
- increased life due to hard surfaces as wear protection
- good corrosion protection and high resistance to many chemicals with coating thicknesses greater than 30 µm
- protection against tribocorrosion
- protection against standstill marks (false brinelling)
- low friction coefficient, good sliding characteristics
- anti-adhesive characteristics

Common applications

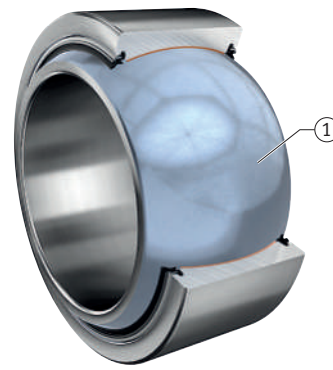
Applications with high wear load in the automotive and industrial sectors:

- spherical plain bearings
- shafts
- bearing components and engine components

☒ 23 Characteristics

Feature	Coating
	Durotect CM, Durotect CMT
Composition	Hard chromium
Color	Silver (lustrous)
Structure	Microcracked hard chromium layer, initial roughness substantially maintained
Layer thickness	0.1 µm to 500 µm (depending on the application)
Hardness	850 HV to 1100 HV
Temperature resistance	Color stable up to +300 °C
	Hardness stable up to +700 °C

26 Radial spherical plain bearing GE60-UK-2TS, maintenance-free



000A232B

- 1 Inner ring coated with Durotect CMT

27 Application example with high wear load: Spherical plain bearing in excavator



000A20E3

- 1 Spherical plain bearing coated with Durotect CMT

3.3.6 Durotect NP

Nickel-phosphorus alloy

Coating process

- autocatalytic chemical deposition

Advantages, benefits

- almost uniform layer distribution over the entire component surface
- combination of wear protection and corrosion protection
- corrosion protection for maritime applications
- high chemical resistance to aggressive media
- compatible with food under certain conditions
- matching of friction characteristics and wear characteristics possible through the inclusion of PTFE particles or hard substance particles (diamond, SiC)
- increased hardness by means of thermal post-treatment

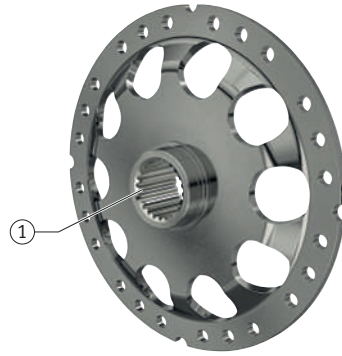
Common applications

- guide rings of spherical roller bearings
- spherical plain bearings
- housings for the food industry
- needle roller and cage assemblies
- thrust washers

24 Characteristics

Feature	Coating
	Durotect NP
Composition	Nickel-phosphorus
Color	Metallic silver, slight yellow tinge
Layer thickness	
With corrosion protection	5 µm to 75 µm (non-maritime application) > 75 µm (maritime application)
With tribological stress	> 5 µm (depending on requirement)
Phosphorus content	
2 % to 5 %	Wear protection
6 % to 9 %	General application for wear resistance and corrosion resistance
10 % to 13 %	Corrosion protection
Hardness (depending on phosphorus content)	
Standard	500 HV to 600 HV 0.1
With heat treatment	750 HV to 1000 HV 0.1
Magnetism	Magnetic effect up to 9 % phosphorus

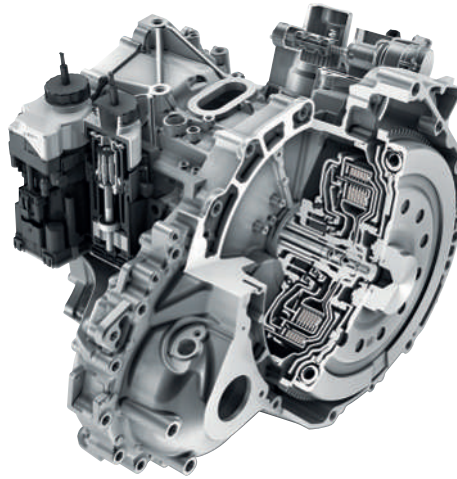
28 Clutch hub



000A130B

1 Inner tooth set coated with Durotect NP

29 Application example, clutch system



000A0FAC

3.3.7 Durotect C

Copper coating

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- improvement in tribological characteristics
- improvement in emergency running behavior in conditions of lubricant starvation
- temperature dissipation from functional area
- use at high speeds and velocities
- increased electrical conductivity

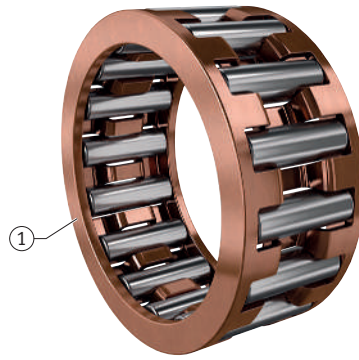
Common applications

- sheet steel cages for connecting rod bearing arrangements in two-stroke and four-stroke engines
- cages for aerospace applications
- large size bearing cages
- plug contacts

☐ 25 Characteristics

Feature	Coating
	Durotect C
Composition	Pure copper layer
Color	Copper
Layer thickness	2 µm to 50 µm (depending on requirement)

30 Needle roller and cage assembly for connecting rod bearing arrangements



000A0FC8

1 Cage coated with Durotect C

31 Application example, motorcycle



000A08FA

3.3.8 Durotect S

Silver coating

Coating process

- electroplating method
- subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement)

Advantages, benefits

- improvement in tribological characteristics
- improvement in emergency running behavior in conditions of lubricant starvation
- temperature dissipation from functional area
- use at high speeds and velocities
- improved tribological performance in comparison with Durotect C
- higher electrical conductivity

Common applications

- sheet steel cages for connecting rod bearing arrangements in two-stroke and four-stroke engines
- cages for aerospace applications
- large size bearing cages

26 Characteristics

Feature	Coating
	Durotect S
Composition	Silver coating on copper bonding layer
Color	Silver
Layer thickness	≥ 2 μm (depending on requirement)

32 Engine bearings for aircraft, FAG three point contact bearing



000A3A55

33 Application example, aircraft, engine



001AD7A2

3.3.9 Durotect H

Metallic coating for dimensional correction (depending on application)

Coating process

- thermal spraying

Advantages, benefits

- material application for dimensional correction (recreation of damaged or worn surfaces)
- additional increase in wear resistance

Common applications

- large size bearings

27 Characteristics

Feature	Coating
	Durotect H
Composition	Metallic coating, coating material dependent on specific application
Color	Metallic
Layer thickness	Selectable, dependent on necessary dimensional correction
Hardness	Selectable, depending on hardness of base material

3.3.10 Durotect HT

Metallic coating

Coating process

- thermal spraying

Advantages, benefits

- increase in wear resistance of surfaces under high stress
- increase in static friction coefficient
- setting of dynamic friction coefficient

Common applications

Engine components:

- synchro rings
- camshaft phasing units
- sprockets

28 Characteristics

Feature	Coating
	Durotect HT
Composition	Metallic coating, coating material dependent on specific application (e.g. CrO ₂ , WC-Co, SiC)
Color	Metallic (depending on coating material used)
Layer thickness	50 µm to 500 µm (depending on the application)
Hardness	> 650 HV, depending on coating material, hardnesses > 1000 HV also achievable

3.3.11 Durotect HA

Aluminum oxide layer on aluminum alloys

Coating process

- electrolytic oxidation (anodizing)

Advantages, benefits

- increase in wear resistance of aluminum and aluminum alloys through increase in surface hardness
- increased chemical resistance
- improved sliding characteristics as a function of running partner
- increased corrosion protection
- very uniform layer thickness distribution (excluding narrow gaps)

Common applications

- aluminum sliding sleeves in clutch bearings
- aluminum cages for aerospace applications
- bonding layer for paints as a result of high surface roughness in uncompressed Durotect HA type
- housings for hydraulic clutch systems

☐29 Characteristics

Feature	Coating
	Durotect HA
Composition	Aluminum oxide
Structure	Capillary pillar structure
Color	Silver to mouse gray (matt, depending on alloy), in uncompressed type, entire oxide layer can be colored as required
Layer thickness	2 µm to 25 µm (of which 50 % as volume increase), wear protection at and above 15 µm
Hardness	350 HV to 600 HV (mixed hardness, depending on alloy)
Temperature resistance	Up to +400 °C

34 Aluminum cages, coated with Durotect HA



000A2107

35 Application example, brake flap drive on aircraft wing



000A08F3

3.3.12 Durotect P

Polymer-based coating

Coating process

- dipping method:
 - complete coating of individual components
- spraying method:
 - complete or partial coating
- curing temperature dependent on paint system, from room temperature to approx. +250 °C

Advantages, benefits

- increase in sliding capability by means of solid lubricants (MoS₂, graphite, PTFE) in unlubricated state; solid lubricants are released when layer is subjected to load
- reduction in friction coefficient to $\mu < 0.1$ under axial displacement of bearing rings
- special types can also be used for high-temperature applications
- current insulation in low voltage range
- sliding aid for pressing-in
- self-lubricating layer

Common applications

- spherical roller bearing outer ring outside surface
- cages
- guide sleeves

30 Characteristics

Feature	Coating
	Durotect P
Composition	Polymer-based coating
Color	Black
Layer thickness	15 µm to 100 µm

36 Examples of components coated with Durotect P



001ABD04

4 Coating systems for surfaces subjected to high tribomechanical stresses

4.1 Triondur coating systems

With the continuing increases in energy efficiency not only in modern combustion engines but also in the entire energy chain (from a wind turbine gear to any moving part in a vehicle), there are increasing demands on the tribological load carrying capacity of components.

With the aid of modern PVD and PACVD coating processes as used for the Triondur coatings from Schaeffler, it is possible to achieve significant increases in the performance capability of components subjected to high tribological stresses. This gives potential for increased life, minimized friction, and lightweight design. Triondur coating systems thus make an active contribution to conservation of the environment and resources as well as sustainability.

Triondur coating systems are created under vacuum by means of physical vapor deposition (PVD) and plasma-assisted chemical vapor deposition (PACVD). Through suitable selection of the coating composition and the deposition process, Triondur coating systems are ideally matched to the specific application. From elastic coating systems for rolling contacts to extremely hard wear protection coatings, as well as chemical resistance through to targeted reactions for lubricant film formation with selected oil additives, there are many possibilities for optimization.

Triondur coating systems are more than just a coating: they are coating systems that, on the basis of individually matched coating processes and components of optimized design, take account of all necessary aspects from manufacture to application.

4.2 Coating methods

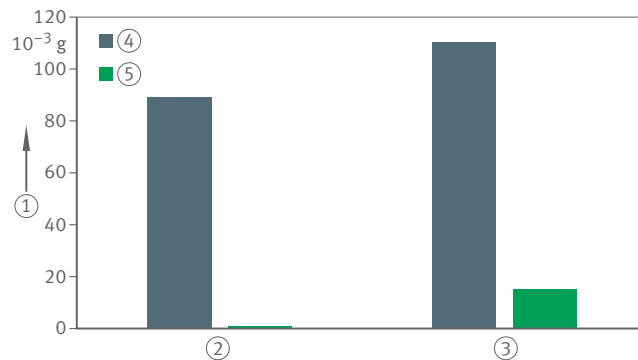
Triondur coating systems for rolling bearings

In rolling bearings, the use of coated rolling elements can achieve a significant increase in operating life, especially if the bearing is subjected in the application to slippage and lubricant starvation.

Coated cylindrical rollers that have been tested under extreme lubricant starvation in a test rig run, exhibit significantly improved performance in comparison with uncoated reference parts. Gravimetric evaluation of the wear shows that the use of Triondur C has almost eliminated wear of the rolling element. At the same time, wear of the uncoated thrust washers has been significantly reduced.

A further application for Triondur coating systems in rolling bearings is the coating of large end faces of tapered rollers in order to reduce friction and wear in contact with the rib of the inner ring.

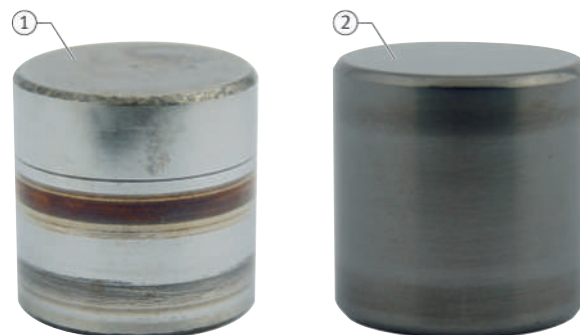
37 Test rig run with extreme lubricant starvation



001AC523

1	Wear	2	Rolling elements
3	Thrust washers	4	Uncoated
5	Coated		

38 Rolling element after test rig run



000C80B9

1	Uncoated	2	Coated with Triondur C
---	----------	---	------------------------

Triondur coating systems for engine components

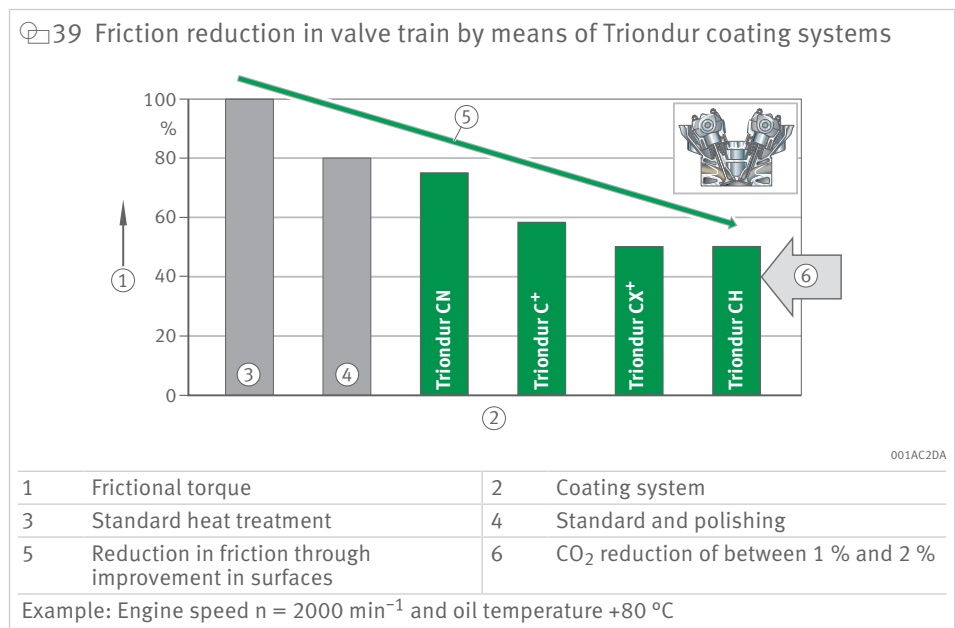
Through the use of Triondur coating systems, it has been possible to continuously reduce friction at the tappet/cam contact in the valve train.

Until about 15 years ago, the use of purely heat treated tappets was the state of the art. Through the use and continuous development of Triondur coating systems, it has been possible to reduce frictional torque using Triondur by up to 50 %. This corresponds to a reduction in CO₂ emissions of between 1 % and 2 %.

Triondur coating systems are used not only on mechanical tappets but also on other contacts subjected to strong loads.

Examples:

- cam rollers and valve contact surfaces for roller type finger followers
- plain bearing components
- pistons in the high pressure area of fuel pumps



4.3 Coating variants

4.3.1 Triondur C

Metal-containing hydrogenated amorphous carbon coating

Coating process

- PVD method

Advantages, benefits

- high level of protection against abrasive and adhesive wear together with preservation of the friction partner
- dry friction against steel is reduced by up to 80 %
- considerable increase in the operating life of the entire tribological system if only one friction surface is coated
- can withstand the high contact pressures that occur in rolling bearing applications due to its highly ductile coating structure

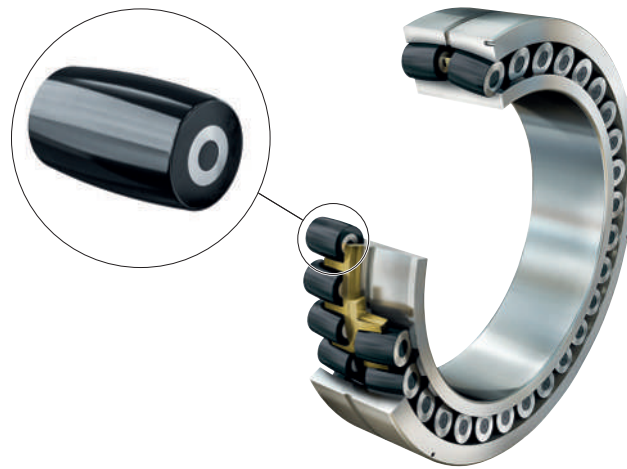
Common applications

- bearing components such as rolling elements, inner rings, outer rings, and thrust bearing washers
- yoke and stud type track rollers

31 Characteristics

Feature	Coating Triondur C
Composition	a-C:H:Me (functional layer)
Color	Anthracite
Layer thickness	0.5 µm to 4 µm
Friction reduction	Up to 80 % with DLC/steel in comparison with steel/steel (in dry state)
Hardness	> 1200 HV

40 Asymmetrical spherical roller bearing for the bearing arrangement of the rotor shaft in a wind turbine, barrel roller coated with Triondur



000A3A96

41 Application example, spherical roller bearings in wind turbines



000A0A79

4.3.2 Triondur C+

Hydrogenated amorphous carbon coating

Coating process

- PVD and PACVD methods

Advantages, benefits

- coating systems for very high tribomechanical stresses
- high resistance to abrasive wear and high level of protection against adhesive wear
- very high mechanical strength
- highly suitable for components subjected to high tribological stresses with lubricant starvation

Common applications

- engine components such as tappets or finger followers
- injection components such as pump and control pistons, nozzle needles

32 Characteristics

Feature	Coating
	Triondur C+
Composition	a-C:H (functional layer)
Color	Black
Layer thickness	2 μm to 4 μm
Friction reduction	Up to 85 % with DLC/steel in comparison with steel/steel (in dry state)
Hardness	> 2000 HV

42 Control piston for diesel injectors



000A7EA6

4.3.3 Triondur CX+

Modified hydrogenated amorphous carbon coating

Triondur CX+ is a modified and nanostructured coating system.

Coating process

- PVD and PACVD methods

Advantages, benefits

- very precise adaptation possible to the tribological requirements present
- best combination of friction minimization, tribochemical resistance and wear protection of all coating systems

Common applications

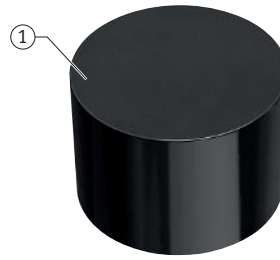
Engine components:

- finger followers
- tappets
- finger follower lever stud
- cages in piston drive

33 Characteristics

Feature	Coating
	Triondur CX+
Composition	a-C:H:X (functional layer)
Color	Black
Layer thickness	2 µm to 4 µm
Friction reduction	Up to 85 % with DLC/steel in comparison with steel/steel (in dry state)
Hardness	> 2000 HV

43 Tappet TSTM



0009E247

1 Sliding layers coated with
Triondur CX+

44 Switchable finger follower



000A25E8

1 Outer lever coated with
Triondur CX+

4.3.4 Triondur CH

Tetrahedral hydrogen-free amorphous carbon coating

Coating process

- PVD method

Advantages, benefits

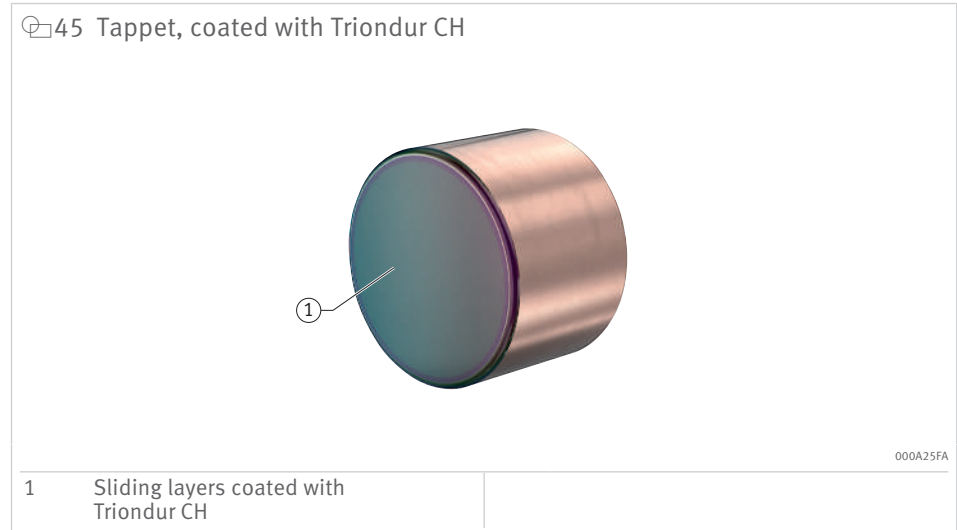
- due to its high hardness, Triondur has the highest resistance of all Triondur CH coatings
- in dedicated tribological systems with appropriately matched lubricants, Triondur CH gives the most effective action and provides the maximum reduction in friction as well as maximum protection against wear

Common applications

- tappets

34 Characteristics

Feature	Coating
	Triondur CH
Composition	ta-C (functional layer)
Color	Greenish
Layer thickness	0.5 μm to 1 μm
Friction reduction	Up to 85 % with DLC/steel in comparison with steel/steel (in dry state)
Hardness	> 4000 HV



4.3.5 Triondur CN

Chromium nitride coating

Coating process

- PVD method

Advantages, benefits

- particularly high hardness and ductility
- high wear resistance and very good oil wetting behavior
- for parts subjected to high frictional energies
- hard chromium substitute, chromium(VI)-free

Common applications

- rolling elements
- maintenance-free spherical plain bearings

35 Characteristics

Feature	Coating
	Triondur CN
Composition	Chromium nitride (functional layer)
Color	Silver
Layer thickness	1 µm to 4 µm
Friction reduction	Up to 20 % with Triondur CN/steel in comparison with steel/steel (in dry state)
Hardness	> 2200 HV

46 Pivoting cradle bearing, coated with Triondur CN



4.3.6 Triondur TN

Titanium nitride coating

Coating process

- PVD method

Advantages, benefits

- high protection against abrasive wear
- wear protection of components in sliding contact

Common applications

- wear protection of ribs in engine bearings, especially due to the cage running in contact with the rib

36 Characteristics

Feature	Coating
	Triondur TN
Composition	TiN (functional layer)
Color	Gold
Layer thickness	2 µm to 5 µm
Friction reduction	Up to 20 % with Triondur/steel in comparison with steel/steel (in dry state)
Hardness	> 2000 HV

47 Running surfaces on the inner ring coated with Triondur



000A7380

48 Application example, aerospace



000A2122

4.3.7 Triondur MN

Nano-structured molybdenum nitride coating with metal doping

Coating process

- PVD method

Advantages, benefits

- wear protection and minimization of friction under challenging lubrication conditions
- high hardness and very low friction coefficient in comparison with other nitridic coatings
- very high temperature resistance up to +600 °C
- high tribochemical wear resistance

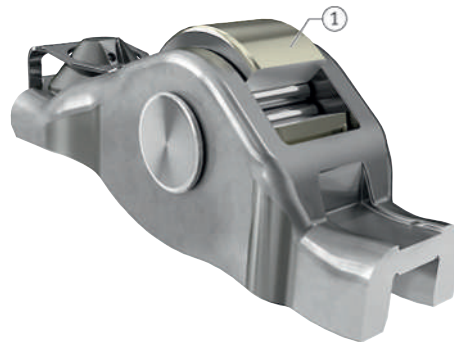
Common applications

- rolling bearing components
- plain bearing components
- engine components

37 Characteristics

Feature	Coating Triondur MN
Composition	CuMoN (functional layer)
Color	Silver
Layer thickness	1 µm to 4 µm
Friction reduction	Up to 85 % with Triondur MN/steel in comparison with steel/steel (in dry state)
Hardness	> 2200 HV

49 Cam roller in finger follower



0015B41A

- | | |
|---|------------------------------------|
| 1 | Cam roller coated with Triondur MN |
|---|------------------------------------|

5 Electrically conductive coatings

5.1 Condulect coating systems

The shift toward e-mobility is leading to a focus on new components such as plug contacts and busbars at Schaeffler. Parts carrying current must satisfy a variety of function-related properties and guarantee these for the entire duration of their functional life. Condulect coatings can be used for the following purposes:

- improve electrical conductivity
- increase chemical resistance to aggressive media (acids, alkalis, harmful gases)
- increase chemical resistance to supposedly noncritical substances (oils, oil mist, water, alcohols, and mixtures of possible media, including at varying temperatures)
- influence thermal conductivity
- improve wear behavior
- change the settling behavior under pressure

5.2 Coating methods

Depending on the application, a wide variety of technologies are available as coating methods. The wet chemical coating method, often also referred to as electroplating or electroplating technology, has established itself as a standard method in this area and is widely used to optimize the surface of current-carrying components. The shape of the component, weight, surface requirements, quantity, and risk of damage determine whether barrel coating (barrel-plated goods), rack plating (rack-plated goods) or, where necessary, coil coating can be used.

Coating type and coating variants

A surface coating that is matched to the substrate is a key criterion for the later planned function and anticipated life of the contact connection. Various coating variants or combinations of diverse coating materials are required or possible, depending on the base material.

Post-treatment

Individual base materials and applied surface materials are subject to a natural chemical surface reaction, which usually manifests itself as oxidation occurring close to the surface (tarnishing behavior). The reaction products formed in this process are generally undesirable, as visually identifiable and, in particular, technical properties are impaired. Various methods are available for reducing these reactions, which are presented as examples below.

- Chemical anti-tarnish protection:
 - octadecanethiol (ODT)
 - hexadecanethiol (HDT)
 - mixture
- Metallic anti-tarnish protection:
 - Sn, Pd, or Cr base
 - no organic components
- Mechanical processing:
 - brushing with fleece, sponge, or disk support
- Heat treatment:
 - thermal structural change

Combination of different metal contact surfaces

Conductect coating materials are subject to restrictions in terms of their combined use, and react under special conditions and as a result of different electro-chemical potentials. A decision on the intended component surface must be tailored to the later application. In principle, future contact partners should be taken into account as early as the design phase.

An initial insight into commonly used coatings and the application areas considered in practice to date is provided in the following sections.

5.3 Coating variants

5.3.1 Conductect ES

Silver coating

Coating process

- electroplating method

Advantages, benefits

- extremely high electrical conductivity
- solder bonded and bondable
- for use in areas subjected to high oscillation loads
- applications required to transmit high currents/current loads (at > 30 A as a substitute for Sn)

Common applications

- automotive engine compartment applications
- control unit bonding

☐ 38 Characteristics

Feature	Coating
	Conductect ES
Composition	Silver
Layer thickness	2 µm to 4 µm, 3 µm to 6 µm, or 4 µm to 6 µm
Hardness	70 HV to 90 HV (90 HV up to max. 120 HV for hard silver)

5.3.2 ConduTECT EG

Gold coating

Coating process

- electroplating method

Advantages, benefits

- no surface change in atmospheric environments
- high abrasion resistance
- low electrical contact resistance, even at low voltages ($< 1\text{ V}$)
- for use in systems with extreme ambient conditions, such as high temperatures, high pollutant loads, high oscillation loads, or high connector mating frequency

Common applications

- plug connections with high safety implications
- applications involving a large number of mating cycles
- bonding gold in semiconductors

39 Characteristics

Feature	Coating
	ConduTECT EG
Composition	Gold
Layer thickness	0.1 μm to 5 μm (0.5 μm to 2 μm as hard gold)
Hardness	80 HV to 110 HV (140 HV to 170 HV as hard gold)

5.3.3 ConduTECT EN

Nickel coating

Coating process

- electroplating or chemical method

Advantages, benefits

- good chemical resistance
- improved corrosion resistance
- ferromagnetic properties
- low diffusion tendency with Cu, Sn, Au, and Ag
- simple and inexpensive deposition processes
- global availability

Common applications

- assists with wear-resistant surface specification
- for areas subjected to corrosion
- diffusion barrier
- for use as an intermediate layer
- plug contacts for moderate currents

40 Characteristics

Feature	Coating
	ConduTECT EN
Composition	Nickel
Layer thickness	1 µm to 5 µm (< 1 µm as flash layer)
Hardness	300 HV to 750 HV (due to the process)

5.3.4 Condulect ET

Tin coating

Coating process

- electroplating method

Advantages, benefits

- possibility of large layer thicknesses due to high-speed deposition
- frequently used contact metal in the automotive sector
- soldering aid
- often with Cu (on brass) or Ni intermediate layer
- simple process control

Common applications

- busbars
- if Au and Ag are not required or prescribed
- soldered connections or weld connections
- automotive plug connectors with a small number of mating cycles

41 Characteristics

Feature	Coating
	Condulect ET
Composition	Tin
Layer thickness	0.5 μm to 5 μm (depending on requirement) > 5 μm for whisker reduction
Hardness	10 HV to 25 HV

5.3.5 ConduTECT EC

Copper coating

Coating process

- electroplating method

Advantages, benefits

- improved adhesion of subsequent coatings on steel and copper-containing substrates

Common applications

- as intermediate layer or bonding agent
- printed circuit boards

42 Characteristics

Feature	Coating
	ConduTECT EC
Composition	Copper
Layer thickness	1 µm to 5 µm (< 1 µm as flash layer)
Hardness	70 HV bis 250 HV (electrolyte-dependent)

6 Coating systems for the conversion and storage of energy

6.1 Enertect coating systems

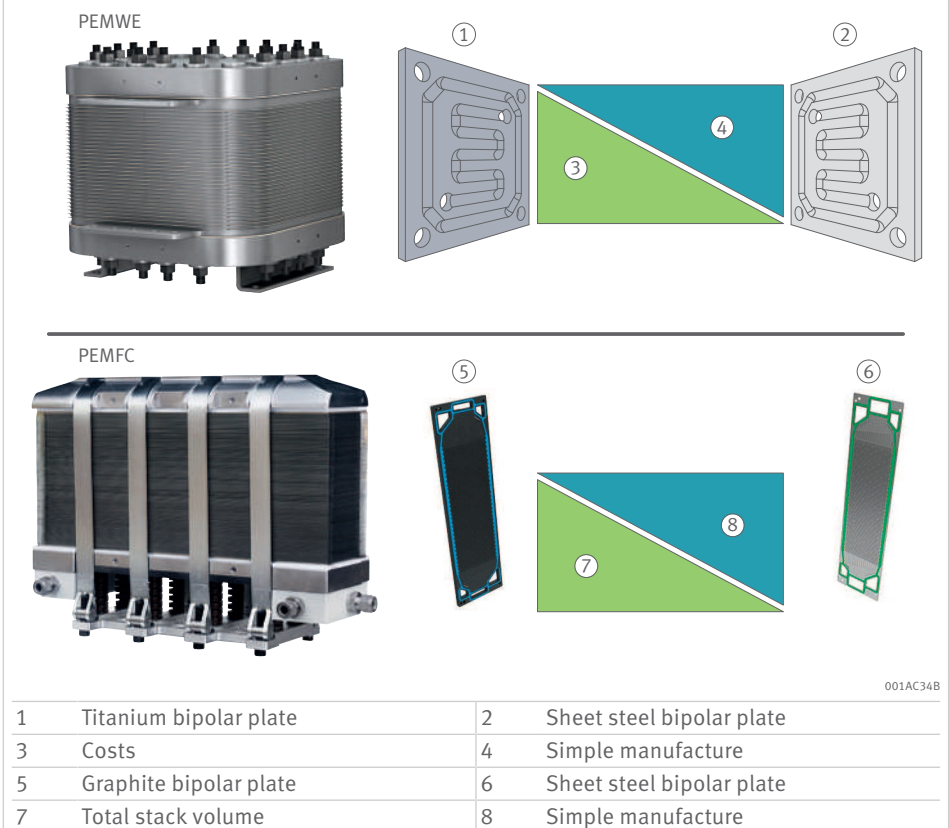
Schaeffler solutions can be found at various points in the hydrogen energy chain, from the extraction of renewable energies through to the production of green hydrogen using electrolyzers and its subsequent use in areas such as fuel cell technology. Schaeffler is already developing components in this area for PEMWE (Proton Exchange Membrane Water Electrolyzer) and PEMFC (Proton Exchange Membrane Fuel Cell), such as bipolar plates (BPP), which, when layered into so-called stacks, form the core of a PEMWE or PEMFC system.

6.2 Coating methods

Steel bipolar plates

Conventional bipolar plates (BPP) are usually made from graphite, graphite compound materials, or expensive metals such as titanium. All of these materials not only present considerable disadvantages in terms of high costs, challenging production, and weight, but also in terms of their CO₂ footprint. For this reason, the focus of material-based development work side is moving increasingly toward BPP produced from comparatively thin sheet steel.

50 Comparison of conventional and steel bipolar plates for PEMWE and PEMFC



Coating solution

Due to the harsh conditions, the use of protective layers for steel BPP is essential. The coated BPP for use in PWMWE or PEMFC must be capable of satisfying technical requirements, such as electrochemical robustness and low electrical interfacial resistances. Furthermore, the manufacturing step of coating must be suitable for large-scale industrial production and the coated BPP must ultimately have an advantageous CO₂ footprint. With this in mind, coatings both with (Enertect PI and Enertect PI+) and without (Enertect PC+) a precious metal content have been developed for metallic BPP produced from steel. Compared with coatings based on precious metals, the Enertect PC+ coating has a significantly lower CO₂ footprint and is also more cost-efficient with a comparable performance where demands on service life are high.

51 Coating systems for bipolar plates with and without a precious metal content



001AC2FA

1	Enertect PI and PI+	2	Enertect PC+
3	Substrate	4	Top layer containing precious metal
5	Intermediate layer	6	Metallic bonding agent
7	Top layer free of precious metal	8	Optimum performance under aggressive conditions
9	Optimum price/performance ratio	10	90 % cost reduction

6.3 Coating variants

6.3.1 Enertect PI

Coating containing precious metal

Coating process

- PVD method

Advantages, benefits

- low electrical resistance
- high wear resistance
- corrosion protection

Common applications

- components for the conversion and storage of energy

43 Characteristics

Feature	Coating
	Enertect PI
Composition	Coating containing precious metal
Layer thickness	≥ 300 nm

6.3.2 Enertect PI+

Coating with reduced precious metal content

Coating process

- PVD method

Advantages, benefits

- low electrical resistance
- high wear resistance
- corrosion protection
- lower CO₂ carbon footprint compared with Enertect PI

Common applications

- components for the conversion and storage of energy

44 Characteristics

Feature	Coating
	Enertect PI+
Composition	Coating with reduced precious metal content
Layer thickness	≥ 300 nm

6.3.3 EnerTECT PC+

Coating free of precious metal

Coating process

- PVD method

Advantages, benefits

- low electrical resistance
- high wear resistance
- corrosion protection
- significantly lower CO₂ compared with coatings with a precious metal base
- more cost-efficient than coatings containing precious metal with comparable performance

Common applications

- components for the conversion and storage of energy

45 Characteristics

Feature	Coating
	EnerTECT PC+
Composition	Coating free of precious metal
Layer thickness	150 nm to 300 nm

7 Current insulation

7.1 Insutect coating system

Insutect coating systems

When rolling bearings are used in wheelsets and traction motors for rail vehicles, direct current motors, and alternating current motors as well as generators, current passage may occur. Under unfavorable conditions, this leads to damage to the raceways and rolling elements.

7.2 Coating methods

For current insulation, the plasma spray method is used. The aluminum oxide powder used melts during the coating process and is sprayed at high velocity onto the outer ring or inner ring.

The base material must be roughened prior to applying the oxide layer. The oxide layer is then sealed.

Protection against current passage

In order to prevent failure of the bearing, current-insulating bearings are used. This interrupts the passage of current between the housing and shaft. Electrical insulation is possible by, for example, an insulation coating on components (outer ring or inner ring).

- ⚠ In selection of the coating, the electrical and mechanical load profile of the application must be taken into consideration.

52 Current-insulating example bearings



001AC4B1

Insulation coatings

Depending on the requirements of the application, various Insutect A coating variants can be offered from the modular coating tool box. The essential coating characteristics and areas of application of the Insutect A coating system are described below.

7.3 Coating variants

7.3.1 Insutect A

Ceramic coating made from aluminum oxide (Al_2O_3) with sealing

Coating process

- plasma spray method

Advantages, benefits

- direct current resistance up to 1000 M Ω
- layer thickness 120 μm to 200 μm , up to a maximum layer thickness of 700 μm possible at the customer's request
- current insulation provided even in damp environments
- alternating current resistance decreases with increasing frequency; at 100 kHz, for example, the alternating current resistance for bearing type 6314 is still 346 Ω
- additional corrosion protection
- the external dimensions of the bearing correspond to DIN 616:2022; coated bearings are therefore interchangeable with standard bearings
- different coating thicknesses, matched to the planned application, can be applied; depending on the coating system, puncture strengths of up to DC 6000 V can be achieved

Common applications

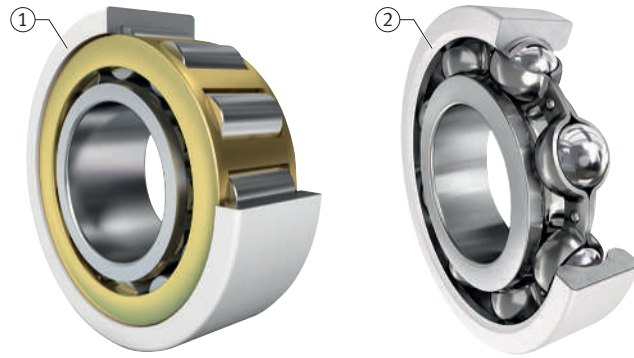
- bearings for electric motors
- traction motor bearings
- wheelset bearing arrangements
- bearings in generators
- marine propulsion systems

An overview of the key parameters for the most common variants of Insutect A is provided in the following table:

46 Characteristics

Feature	Coating		
	J20GA	J20GB	J20GI
Bearing coating	Outer ring	Outer ring	Inner ring
Color	Beige (matt)		
Layer thickness	120 μm	200 μm	120 μm
Operating environment	Dry, damp		
Dielectric strength	3000 DCV		
Ohmic resistance	250 M Ω	400 M Ω	250 M Ω
Impedance (6314, f = 100 kHz)	221 Ω	346 Ω	419 Ω
Possible dimensions			
Inside diameter	–	–	≥ 70 mm
Outside diameter	70 mm to 800 mm	70 mm to 800 mm	Up to 800 mm

53 Current-insulating bearings, outer ring coated with Insutect A



0009E252

1 Cylindrical roller bearing

2 Deep groove ball bearing

54 Application example, Rail



000A3D94

Further information

TPI 206, Current-insulating bearings, <https://www.schaeffler.de/std/1FE8>

8 Sensor technology, measurement of force and torque

8.1 Sensotect coating system

With the innovative thin film sensor technology Sensotect, Schaeffler is introducing intelligent coating systems into the automotive and industrial sectors.

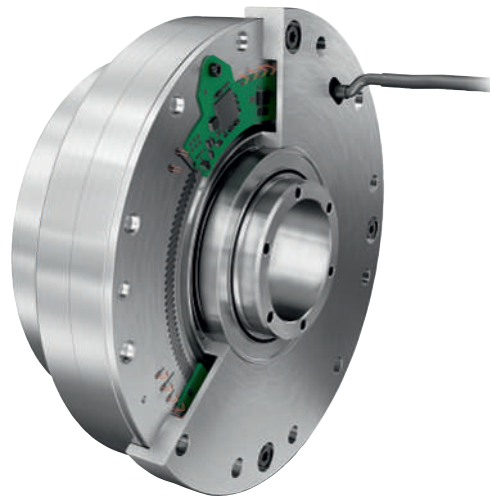
Sensotect allows, with neutral effect on design envelope and in real time, measurement of the load condition at locations where classic sensors such as adhesive bonded strain gauges cannot be used.

The functionality is achieved by means of a strain-sensitive metal coating with a thickness measured in the submicrometer range that is structured by micro-processing. This measurement structure allows the continuous measurement of force and torque during operation.

With the aid of modern thin film technology, the component becomes a sensor and the sensor becomes a component. Due to this measurement technology, it is possible, for example, to determine the torque of drive shafts or in vehicle transmissions very quickly and precisely. Engine power can then be set exactly to the load occurring. In this way, Sensotect makes an important contribution to saving energy and fuel and ultimately helps to reduced CO₂ emissions.

Both the automotive and industrial sectors offer numerous areas of application in which the integrated sensor coating can make a contribution to digitalization.

55 Sensorized precision strain wave gear



001A0E78

8.2 Coating variants

8.2.1 Sensotect

Multi-layer system comprising insulation coating and strain-sensitive metal coating

Coating process

- PVD method and microstructure processing

Advantages, benefits

- very precise measurement of force and torque on functional components where the possibilities associated with conventional methods are limited
- sensor layer is deposited directly on the substrate surface
- measurement possible on 2D and 3D geometries
- sensor technology with neutral effect on design envelope
- no use of adhesives or transfer polymers
- continuous measurement of force and torque during operation
- high sensitivity with very little deviation in hysteresis and linearity
- no temperature deviations
- no aging effects
- wireless transfer of data and energy (telemetry)

Common applications

- bearings
- axles
- shafts
- individual bending beams

47 Characteristics of Sensotect

Feature	Coating
Composition	Multi-layer system comprising insulation coating and strain-sensitive metal coating
Structure	Meander structure
Color	Light gray to beige (matt)
Layer thickness	approx. 10 µm

56 LoadSense pin, coated with Sensotect



**Schaeffler Technologies
AG & Co. KG**

Industriestraße 1 – 3
91074 Herzogenaurach
Germany
www.schaeffler.de/en
info.de@schaeffler.com

In Germany:
Phone 0180 5003872
From other countries:
Phone +49 9132 82-0

All information has been carefully compiled and checked by us, but we cannot guarantee complete accuracy. We reserve the right to make corrections. Therefore, please always check whether more up-to-date or amended information is available. This publication supersedes all deviating information from older publications. Printing, including excerpts, is only permitted with our approval.
© Schaeffler Technologies AG & Co. KG
TPI 186 / 01 / en-US / DE / 2024-03