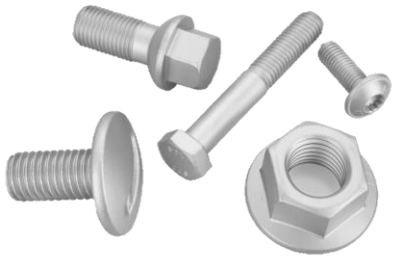
ZINC FLAKE CATING SYSTEM

CSPI Cambridge – Overview - Draft 1

Armin Hadzidedic / March 25, 2020

Technology for tomorrow's solutions

Contents



Zinc Flake Introduction

Zinc flake coating systems

Non Automotive application examples

Wind energy

Agriculture

Construction

+ railway, heavy machinery, off-shore industry...

ATOTECH

Zinc flake coating systems – introduction

Basics

- Zinc flake coatings (**ZFC**) is a non-electrolytic method to create a cathodic protection layer by deposition of a lacquer system
- Zinc flake base coats are highly active systems containing lamellar shaped zinc and aluminum particles in a specialized binder system
- The coatings do not contain heavy metals such as nickel, lead, mercury, cadmium, cobalt or Cr(VI)
- Additional top coats enhance performance and physical characteristics:
  - Increased corrosion protection
  - Controlled coefficient of friction using internal lubricants
  - Choice of various colors

Zinc flake coating systems – introduction

Hydrogen embrittlement

- Fasteners like nuts, bolts and screws are typically constructed from steel
- Typically high strength steels are utilized
- High strength steels are subject to weakening due to exposure to hydrogen
  - Hydrogen embrittlement
- Hydrogen is produced near to parts during zinc or zinc alloy plating
- It is desirable to avoid such hydrogen exposure and embrittlement
- HDG – All source of hydrogen must be considered (IHE), (EHE) and Thermal shock (i.e., *up-quenching*)
- Zinc flake coating systems are non-electrolytic and so generate no hydrogen during coating
  - **Hydrogen embrittlement** is **not an issue for ZFC** systems

Zinc flake coating systems – introduction

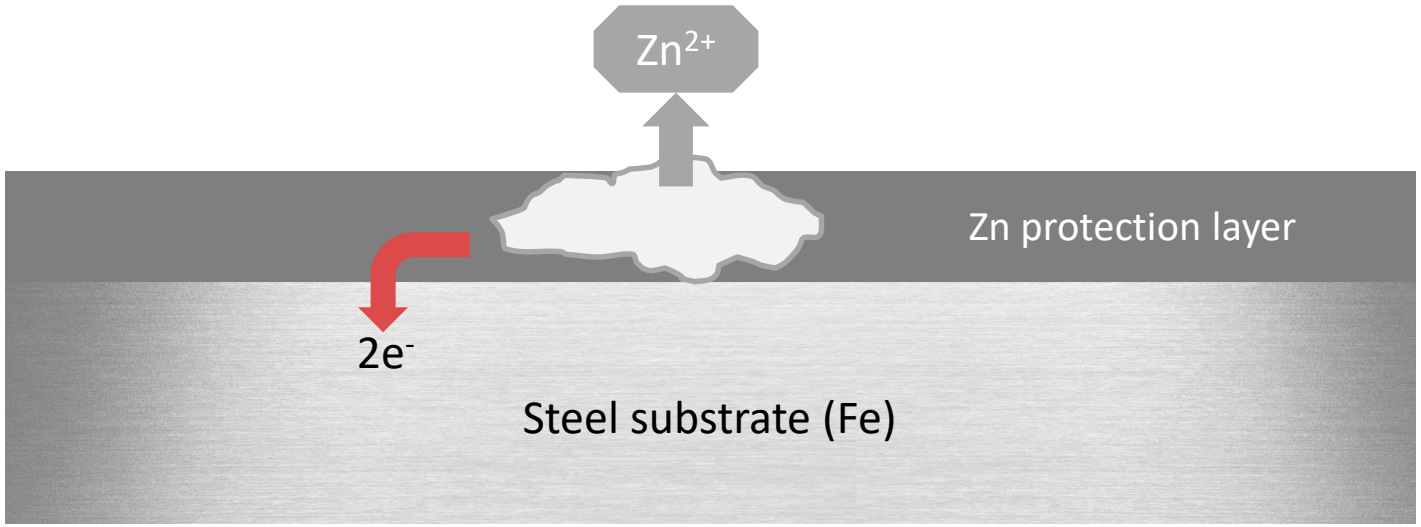
Iron corrosion - background

- Metal corrosion is the deterioration of a metal due to chemical or electrochemical reactions between it and its environment
- Corrosion typically generates oxides of metals
  - Like rust for iron and steel
- Iron corrodes easily to due to its negative value in the electrochemical series and the physical characteristics of its oxidation products (rust)
- We have all seen rusty equipment and parts
- Iron and steel are the most commonly used materials for components and fasteners
  - So we know that components made of these materials need protection from corrosion

Zinc flake coating systems – introduction

Cathodic corrosion protection

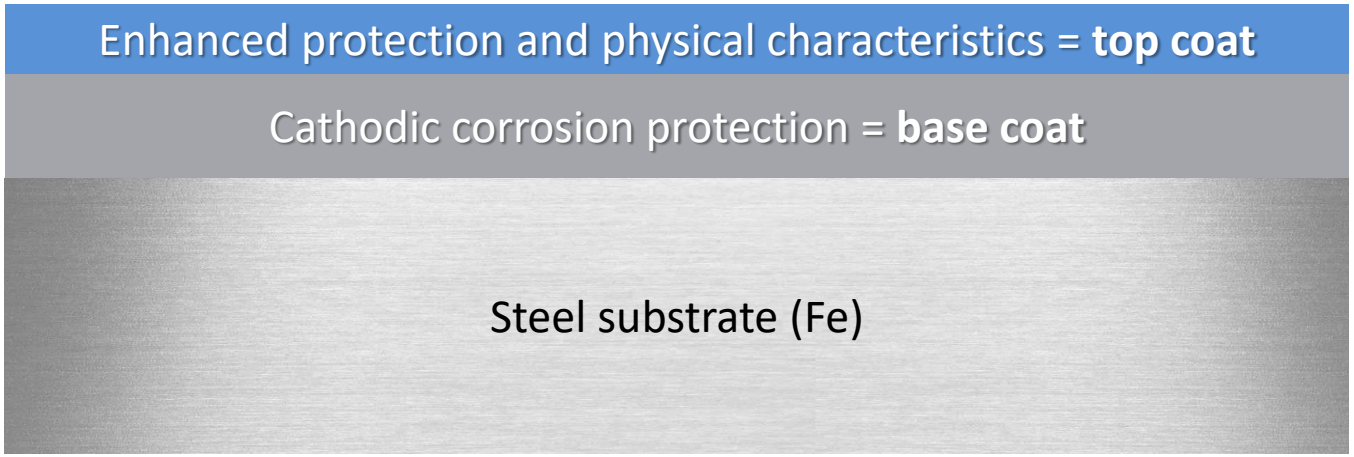
- Simple description: The less noble metal starts to corrode first so protecting the more noble material from corrosion
  - In this case Zn in the coating corrodes before the Fe in the steel substrate
  - During the Zn corrosion electrons are supplied to the steel preventing Fe corrosion
- This cathodic corrosion protection is provided by our zinc containing Zintek® base coats
- The corrosion products of the zinc also tend to form a closed layer so acting as an additional barrier further protecting the substrate from corrosive media



Zinc flake coating systems – introduction

Barrier corrosion protection

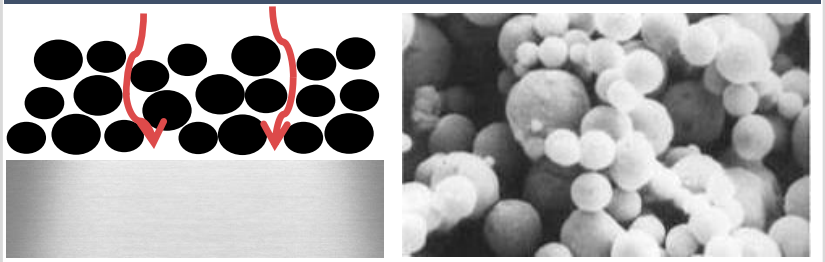
- A further barrier layer (**top coat**) is often applied on top of the cathodic corrosion protection layer (**base coat**)
- The total corrosion protection of the system can be increased by utilizing this additional top coat
- Atotech's top coat range consists of the 3 product series:
  - Techseal®
  - Techdip®
  - Zintek® Top



Zinc flake coating systems – introduction

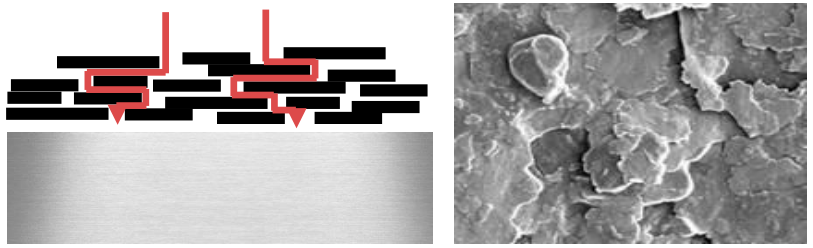
Base coat details – comparison of corrosion media ingress

Zinc dust



- Large gaps between dust particles
- Fast ingress of corrosion media
- Fast corrosion of substrate

Zinc flake



- Small gaps between flakes
- Slow ingress of corrosion media
- Slow corrosion of substrate

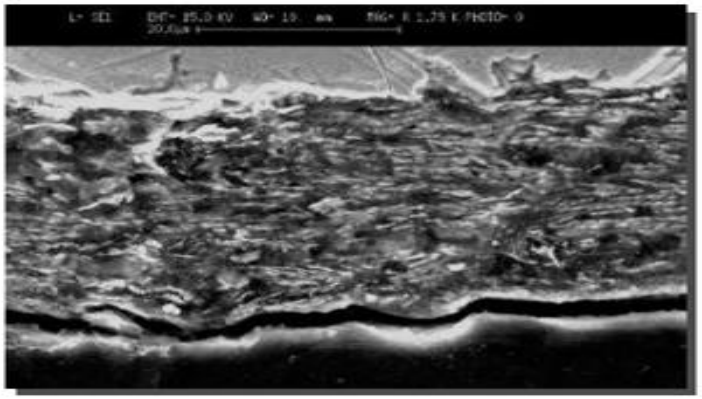
Zinc flake base coats versus powder based have the following advantages:

- Significantly lower layer thicknesses
- Improved barrier protection
- Higher conductivity / connectivity of the Zn flakes gives increased cathodic protection

Zinc Flake coating systems

Base coat details - structure of the Zintek® layer vs HDG structure

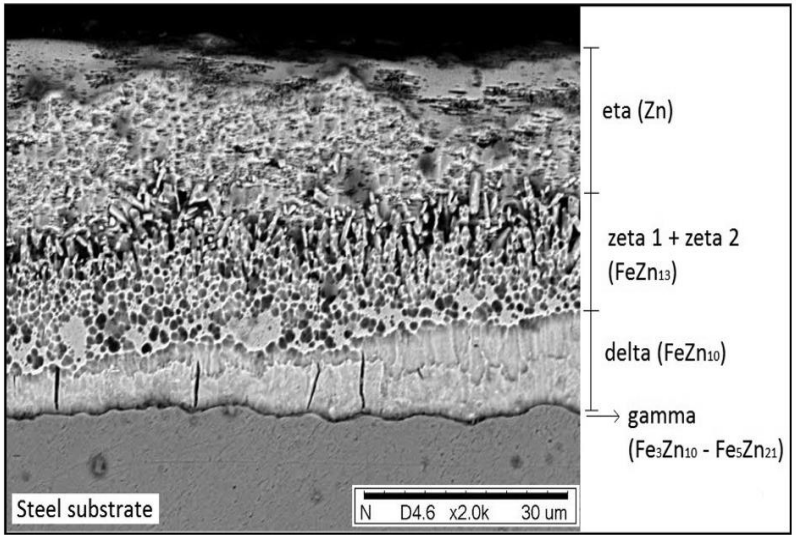
2 layers Zintek® 200 base coat on a steel substrate



Comment: FE REM

Detail ZN Flakes: 9,07 – 10,22 µm

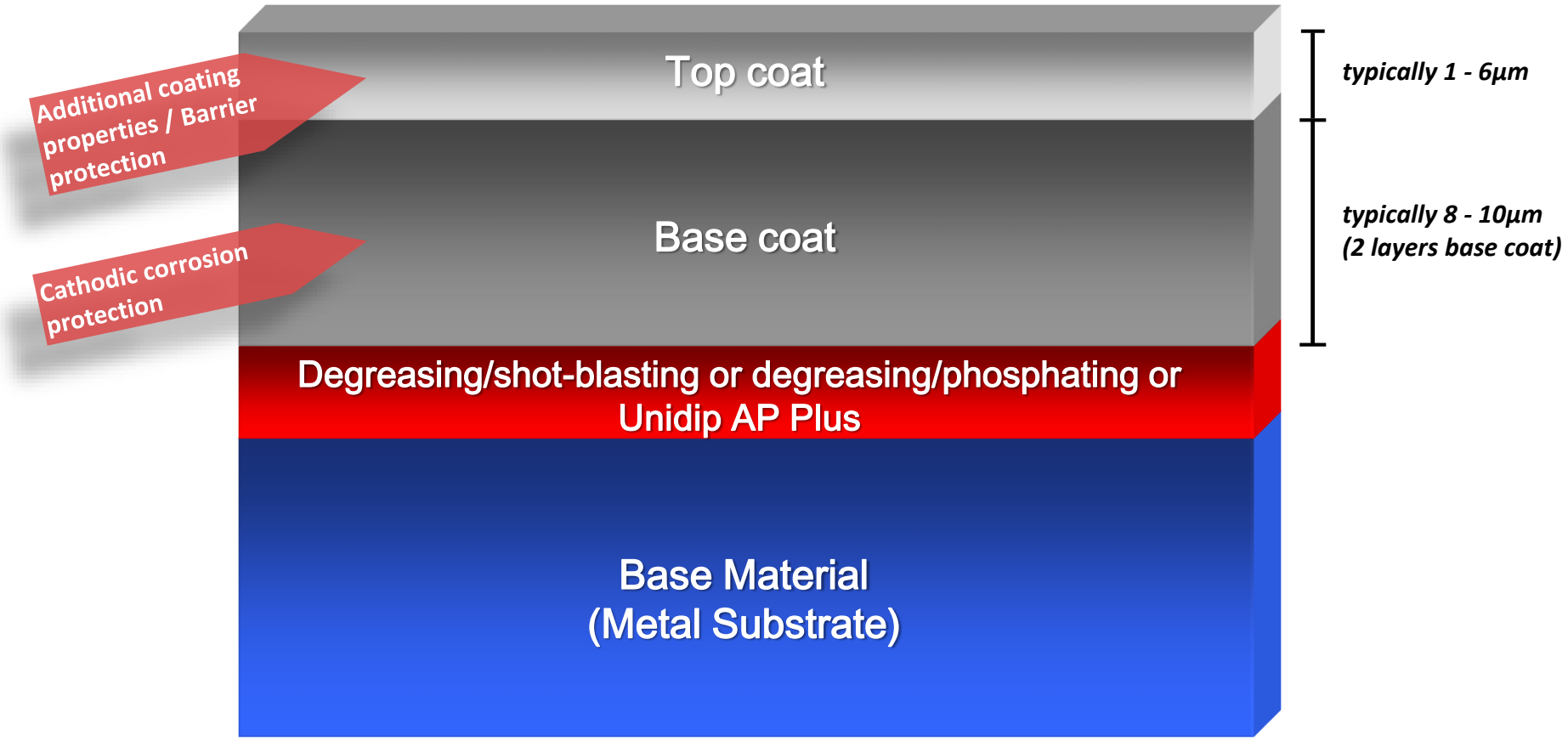
HDG layer on a steel substrate



* Property of America Galvanizers Association

Zinc Flake coating systems - Introduction

Coating layer setup



ZINC FLAKE COATING SYSTEM – PRODUCT RANGE

Zinc Flake coating systems

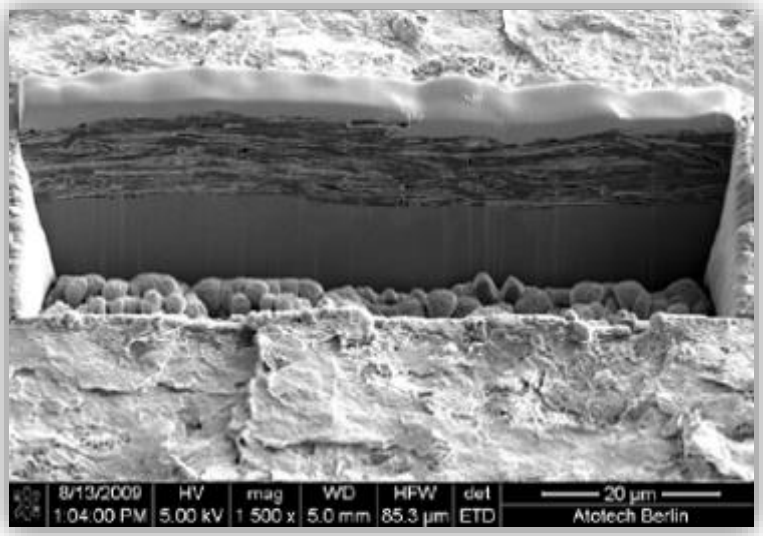
Base coat – Zintek®

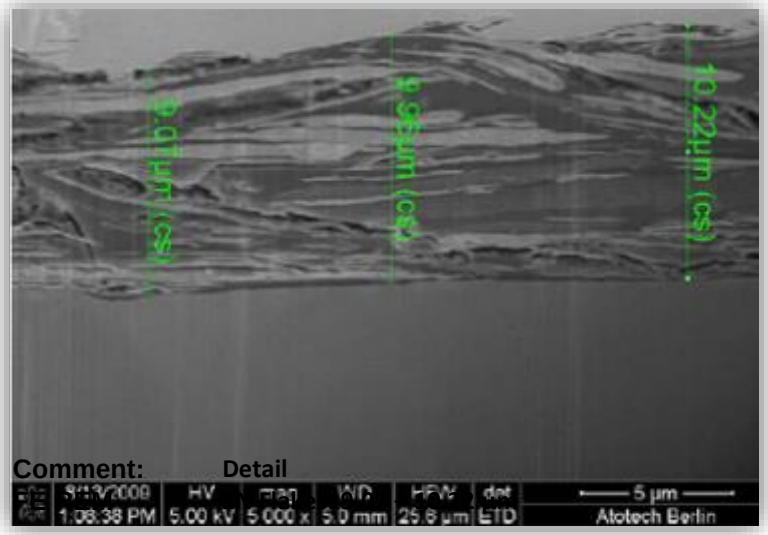
- Zintek® base coats are highly reactive systems containing zinc and aluminum flakes
- The flakes are lying upon each other, close-packed and parallel to the substrate boundary
- The base coats which have to be cured at approx. 230°C do not contain harmful heavy metals such as nickel, lead, mercury, cadmium, cobalt or Cr(VI)
- No acids and no electrical current are used on the parts
  ⇒ No risk of hydrogen embrittlement
- The zinc flake layer acts as a sacrificial anode and provides thereby cathodic protection to the substrate.

Zinc Flake coating systems

Base coat details - structure of the Zintek® layer

2 layers Zintek® 200 base coat on a steel substrate





Zinc Flake coating systems

Base coat range

- **Zintek® 200**
  - Silver premium base coat with excellent corrosion protection
  - Very good adhesion
  - Excellent coverage rate
  - Compatible with all Zintek® Top and Techseal® products
- **Zintek® 300 HP**
  - Black base coat
  - Excellent corrosion protection
  - Increased delay of white corrosion formation
  - Providing a deep black finish in combination with Atotech's top coats

- **Zintek® 400**
  - Silver coating product containing a special organic binder system
  - Highly bendable, paintable and powdercoat-able
  - Protection against corrosion creep
  - In combination with Zintek® CL very low drying temperature (30 -150°C)

Zinc Flake coating systems

Top coat range

Atotech's top coats can be combined with zinc flake base coats as well as electroplated zinc or zinc alloy layers forming multifunctional coatings.

They come in several varieties with features like:

- Water-based or solvent-based
- Enhancement of corrosion protection
- Lubricated versions for controlled torque tension values
- Improved abrasion resistance
- Greater chemical resistance
- Excellent adhesion
- Availability in different colors
- Low drying temperatures (80 – 200°C)
  - depending on the product type

Zinc Flake coating systems

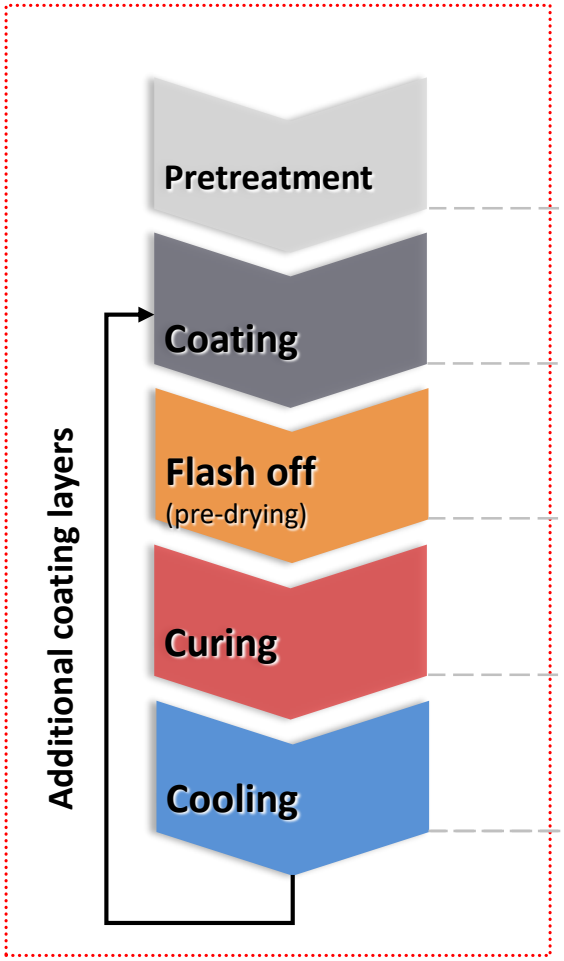
Top coats – Zintek® Top, Techseal®, Techdip®

- **Zintek® Top**
  - Water-based / solvent-based inorganic top coat range
  - Very thin layer thickness (< 1 µm) with a good barrier effect
  - Lubricated versions for controlled torque tension values
  - Available in different colors
  - Excellent performance also on electroplated finishes
- **Techseal®**
  - Solvent-based organic top coat range
  - Lubricated versions for controlled torque tension values
  - Very uniform surface
  - Available in different colors
  - Excellent performance also on electroplated finishes
  - Provides very good chemical and mechanical resistance
- **Techdip®**
  - Water-based / solvent-based organic top coats
  - Enhanced UV-stability
  - Very uniform finish, available in different colors
  - Excellent chemical resistance
  - Good results in the Kesternich test (SO2) 2.0
  - Excellent performance also on plated/passivated surfaces

APPLICATION PROCESS

Zinc Flake coating systems

Application process – Sequence



Process steps	Temperature
Degreasing, shot-blasting, phosphating or Unidip AP Plus	Depends on process
Dip-spin, dip-drain, spray or rack spin coating method	Depends on process
Evaporation of solvents	60 – 110°C
Conveyor belt oven, box oven, inductive curing	180 – 250°C
Cool down of the parts	< 30°C

The dip-spin process sequence (without pretreatment) can be repeated in order to add further coating layers depending on the requirements.

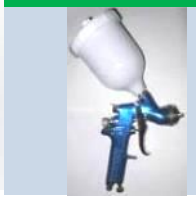
Zinc Flake coating systems

Application process – Overview

Pretreated parts

- **Dip-Spin**
  - **Standard equipment**
    - Conventional centrifuge
    - Tilting centrifuge
  - **Advanced equipment**
    - Planetary centrifuge
    - Horizontal centrifuge
- **Dip-Drain/ Rack-spin**

- **Spray**
  - Conventional spray
  - E-Static spray



Curing

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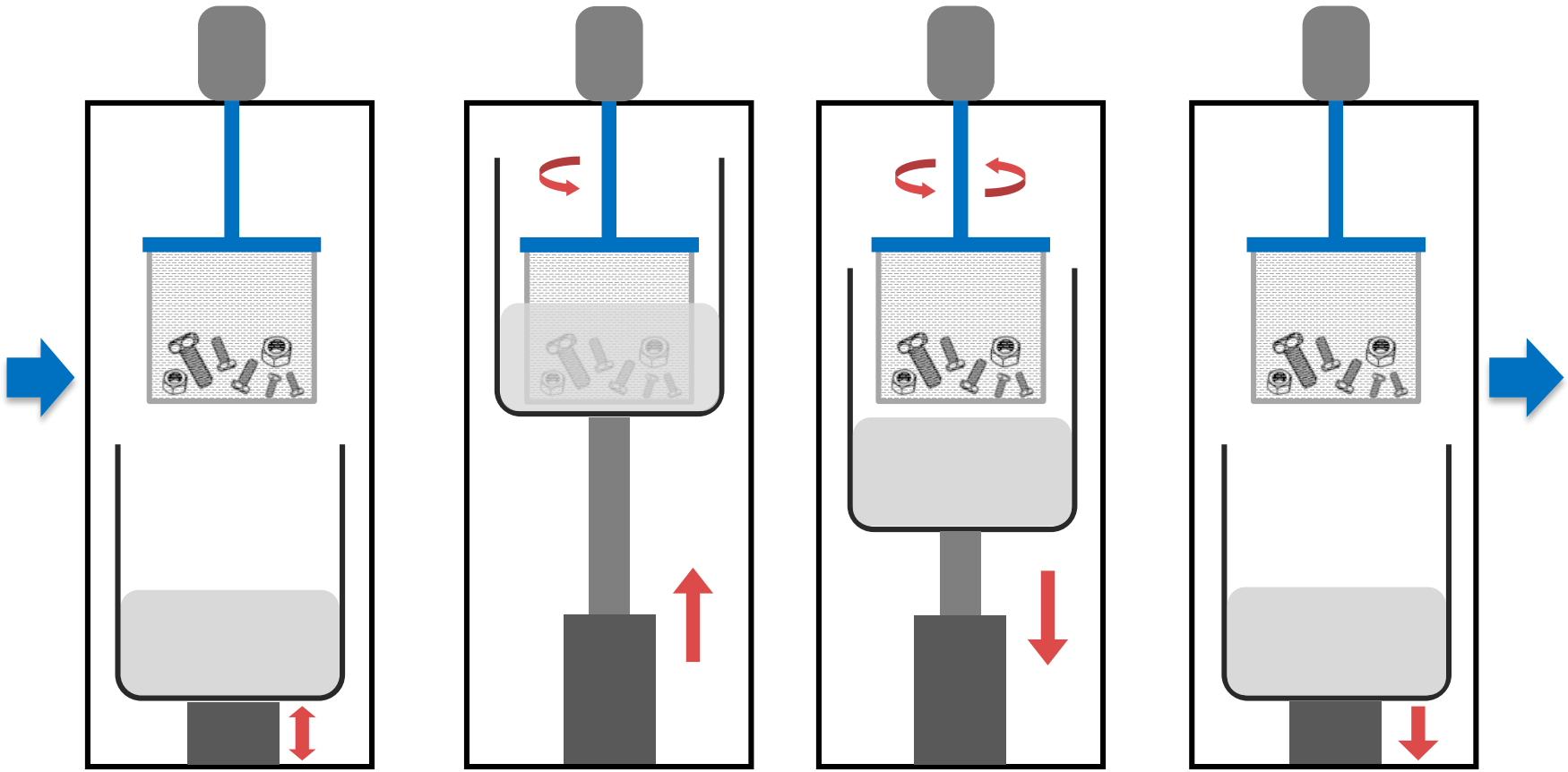
Zinc Flake coating systems

Dip-spin process



Loading of parts

Dip 5 – 30 s at 35 rpm

Spin 8 - 20 s at 250 rpm

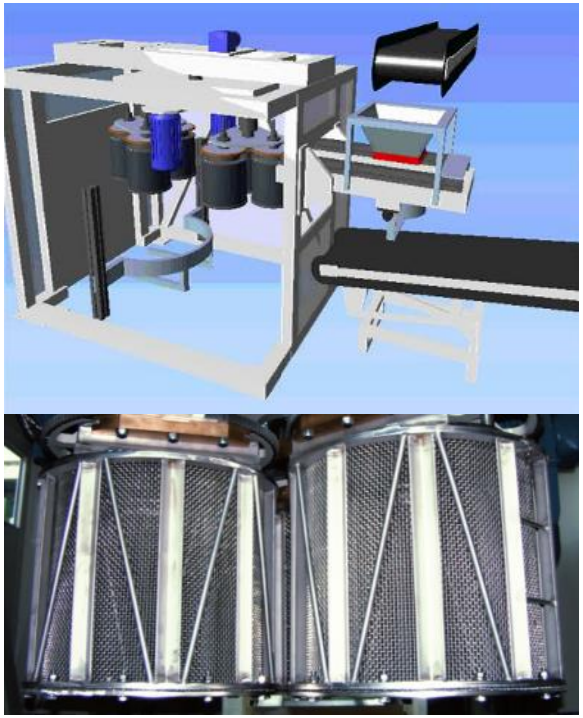
Unloading of parts

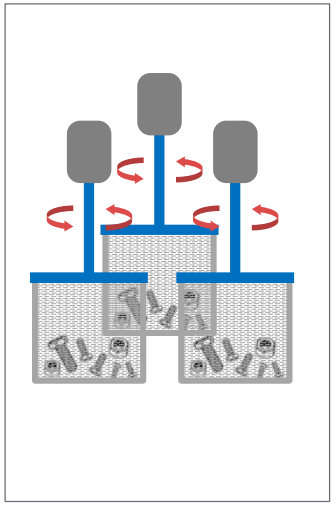
Zinc Flake coating systems

Advanced dip-spin equipment

Planetary centrifuge

- Multiple baskets used, rotating around a center in a planetary motion
- Change of basket position by 180° without tilting
- Minimized coating and part damages because smaller/multiple baskets used
- Very uniform thickness distribution and corrosion protection
- Best coating results even on complex shaped parts, e.g. recess areas, nuts, screws with washers etc.
- In combination with Atotech's Zintek®, Techseal® and Techdip® products excellent results can be achieved





Zinc Flake coating systems

Advanced dip-spin equipment – **LELAND INDUSTRIES**

SIDASA ZT-100+ Planetary centrifuge

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HDG – PROCESS

Zinc flake coating systems

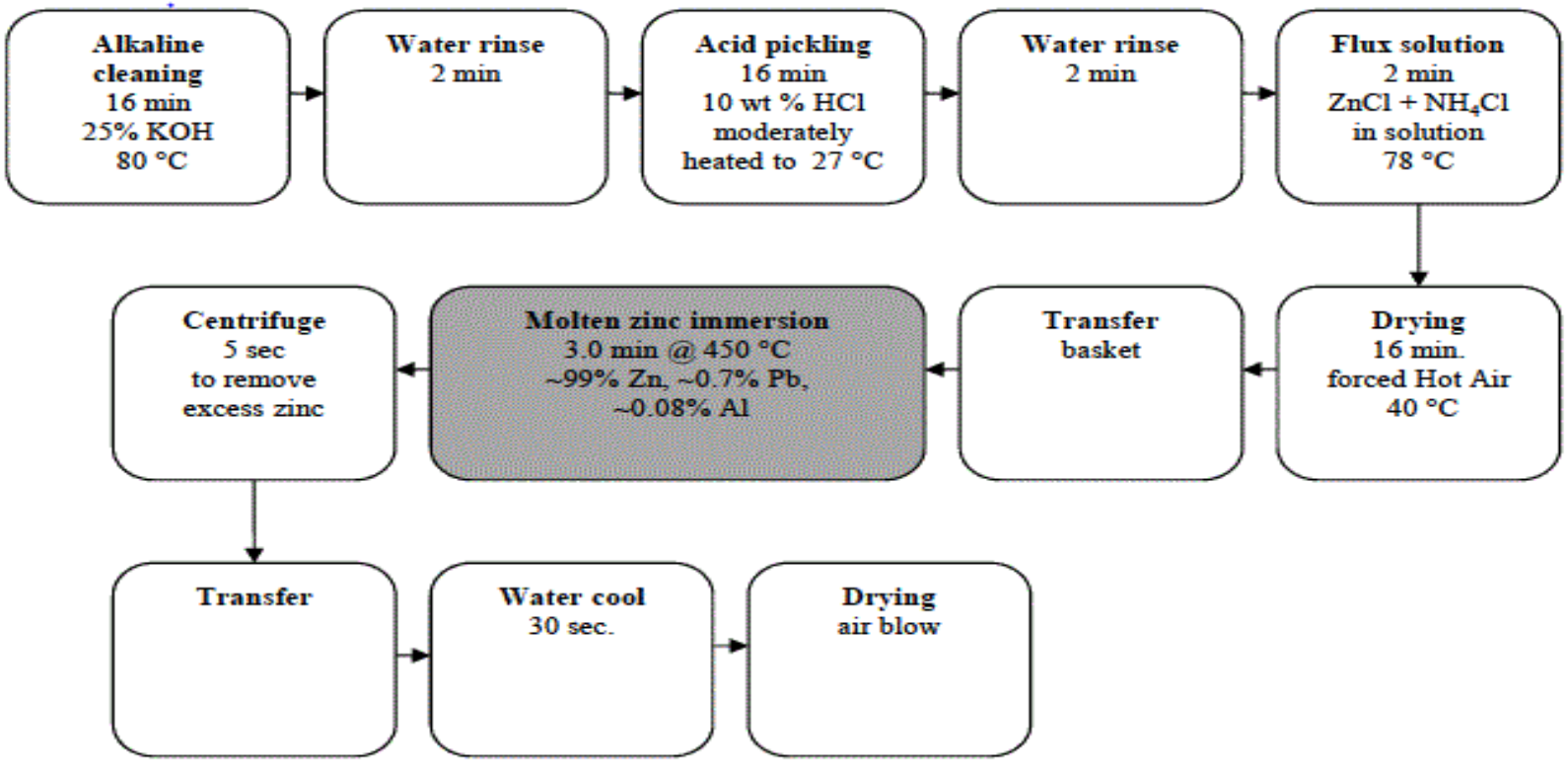
Comparison to other corrosion protection systems

- Hot dip galvanizing
  - High unit weights (40 – 150 µm layer thickness)
  - High process temperature (400 – 500 °C) can deform parts and will reduce steel hardness
  - Small holes in parts can become closed by a film of Zn, threads can be filled, so requiring intensive rework

- E-Coat paints
  - No sacrificial corrosion protection
  - Layer damage will easily lead to red rust and blistering/chipping off of the layer
- Electroplating
  - No deposit on the interior of complex shaped parts
  - No protection inside hollows and shielded areas
  - Risk of hydrogen embrittlement

Zinc flake coating systems

HDG Process Information



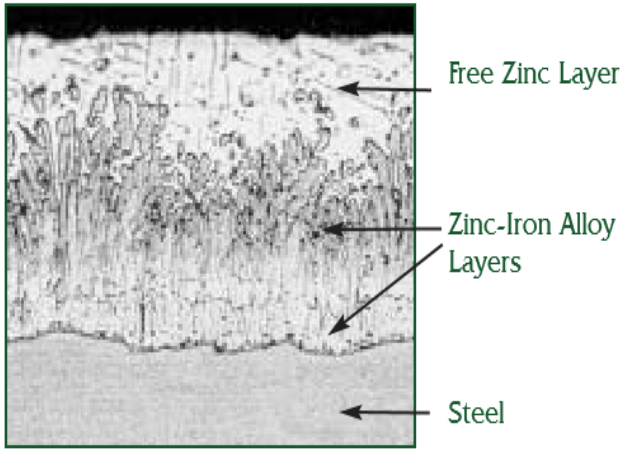
Brahimi, S., et al. *Effect of surface processing variables on hydrogen embrittlement of steel* ***fasteners*** *Part 1: Hot dip galvanizing.* Canadian Metallurgical Quarterly, 2009. **48**(3): p. 293-301.

Zinc flake coating systems

HDG Information – Coating Structure & Thickness

- Hot Dip Galvanizing
  - Porous coating, which may result in corrosion being present prior being visible.
  - Likely contain Lead (Pb) which is toxic.
  - The main drawback is the thickness of the HDG coating. Typical coating thickness on bolts can range from 45 to 90 µm (1.8 to 3.5 mils), which can make standard bolt and nut tolerances difficult to maintain for correct assembly. If bolts are galvanized, then the nuts should be oversized to accommodate the 90 to 180 µm (3.6 to 7.0 mils) increase in bolt diameter after galvanizing. If this is not done, then assembly of the fastener system will either become impossible or will result in the zinc coating being scraped off the thread surface. Either scenario is unacceptable. In addition, depending on the thread pitch of a fastener, the HDG process can often result in non-uniform coating thickness on the threads with thicker coat in the “valleys” and thinner coat in the “peaks” of the thread. This can also result in the coating being removed during fastener assembly.

FIGURE 2: Typical zinc-iron alloy layers



* Property of America Galvanizers Association

Source: Corrosion resistance of Bolt Coatings © 2009 Tyco Electronics Corporation 2009 page 2

Zinc flake coating systems

HDG Information - Nuts

- Hot Dip Galvanizing
  - To minimize HDG Thickness drawback, HDG nuts are re-tapped or rethreaded to remove the zinc coating and provide clearance for the coated bolt. When such a fastener system is assembled, the coating from the bolt is expected to provide galvanic (cathodical) protection for the uncoated nut thread as discussed above. The re-tapping is done on the nut side, as shown in Figure 2, so that no uncoated threads on the bolts are exposed to the environment without galvanized protection. A standard practice in the fastener industry is to galvanize nut blanks and then to tap the threads after galvanizing. This approach, however, opens up a possibility for development of corrosion cells on nut threads if the proper clearance between nuts and bolts is not maintained well or if the HDG coating thickness on bolt threads is not consistent.

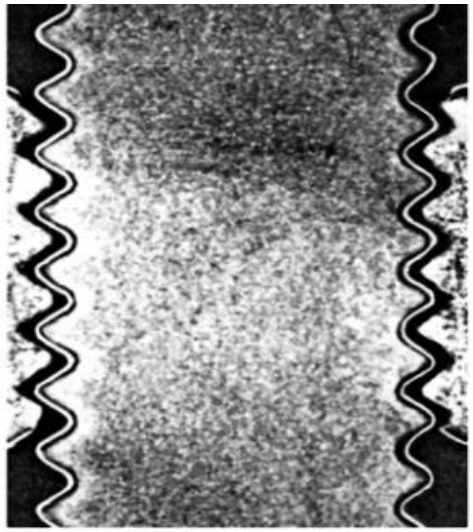


Figure 2. Hot-dip galvanized fastener system. Note absence of coating on nut thread.[1]

Source: Corrosion resistance of Bolt Coatings © 2009 Tyco Electronics Corporation 2009 page 2

Zinc flake coating systems

HDG Information - Hydrogen Embrittlement

The hot dip galvanizing process itself does not introduce hydrogen therefore another source of hydrogen must be considered.

- **Internal Hydrogen Embrittlement (IHE)**
  - Acid pickling is a significant source of hydrogen in coating processes.
- **Environmental Hydrogen Embrittlement (EHE)**
  - Environmental hydrogen is introduced as a result of corrosion.
  - Galvanic corrosion of a sacrificial cathodically protecting coating (e.g HDG) generates hydrogen, which may then be absorbed by exposed steel surface areas (i.e., cathode).
- **Thermal shock (i.e., *up-quenching*)**
  - It has been proved that a significant source of hydrogen is the freeing of trapped residual hydrogen as a result of thermal shock (i.e., *up-quenching*) that occurs when the parts are immersed in molten zinc during galvanizing.
  - The presence of a thick zinc coating prevents hydrogen escaping, instead causing it to accumulate at grain boundaries.
  - The release of trapped hydrogen by up-quenching is therefore a third and potentially very significant source of hydrogen in addition to conventional sources of internal and environmental hydrogen.

Brahimi, S., et al. *Effect of surface processing variables on hydrogen embrittlement of steel* ***fasteners*** *Part 1: Hot dip galvanizing.* Canadian Metallurgical Quarterly, 2009. **48**(3): p. 293-301.

Zinc flake coating systems

HDG Information – T & T

- Hot Dip Galvanizing

  - High variability in the relationship between torque and induced tension. Because of this, torque cannot be used as a reliable method for gauging the required minimum bolt tension. High friction of galvanized surfaces and an inconsistent torque-tension relationship result in high rate of bolt failures in torsion.

Source: Corrosion resistance of Bolt Coatings © 2009 Tyco Electronics Corporation 2009 page 2

PERFORMANCE

Zinc Flake coating systems – Performance

Comparison of corrosion protection methods

	Zn Plating	Zn/Ni Plating	Zinc Flake Coating	HDG	Mechanical Plating	E-coat
Corrosion protection	++ 240 h red rust in Zn deposit	+++ 1000 h red rust	+++ >1700 h red rust	++ high thickness needed	++ high thickness needed	+ No sacrificial, only barrier protection
Hydrogen embrittlement	+ Need heat treatment	+ Need heat treatment	+++ No hydrogen embrittlement	+	+++	+
Brightness	+++	++ alkaline +++ acid	+ ++ with top coat	++	++	
Appearance	++ Iridescent/blue/black/clear	++ Iridescent/blue/black/clear	+++ Multi color finish	+ silver	+	+++ Can be colored
Complex shaped parts	++	++	+++	+ Big parts only, without thread areas	+ Only bulk materials e.g. screws	++

Zinc Flake coating systems – Performance

Comparison of HDG to Zintek®

After 312 Hrs NSST

- Zintek® provides improved corrosion protection at a significantly lower layer thickness

After 1104 Hrs NSST

Zinc Flake coating systems – Performance

Comparison of HDG to Zintek®

HDG

Zintek®

Zinc flake coating systems – Performance

Implementation - Coulvert Bolts

- CORRUGATED STEEL PIPE INSTITUTE – PERFORMANCE

No sample	Sample	300 h	520h	830 h	1000 h	1240 h	1800 h	2050 h	2840 h	3150 h	3375 h	3840 h	4180 h
1	Phos - Leland									RS	RS	RS	RS
2	Undip AP										RS	RS	RS
4	Undip AP (A)									RS	RS	RS	RS
5	Geomet 321 (ASTM F1136)				RS	RS	RS	RS	DC	DC	DC	DC	X
6	Geomet T321 Plus		RS	RS	DC	DC	DC	DC	X	X	X	X	X
7	Dacromet (ASTM F1136)						RS	RS	RS	RS	DC	DC	DC/
8	Dacromet Plus						RS	RS	RS	RS	RS	DC	DC
9	Part 77717 Stainless Steel ASTM F593												
10	Magni Coated Bolts - 2 X B18 RE				RS	RS	RS	RS	DC	DC	DC	DC	X
11	Magni Coated Bolts - BO6J + P126L		RS	RS	DC	DC	DC	DC	X	X	X	X	X
12	Magni Coated Bolts - BO6J + B18		RS	RS	DC	DC	DC	DC	X	X	X	X	X
13	Hot Dipped Galvanized	RS	RS	DC	DC	DC	DC	X	X	X	X	X	X

Table no 3: Evolution of corrosion

Note: Surface coating under attack (marked RS)
Start of corrosion (marked DC)
Total loss of coating (marked X), rust

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Zinc flake coating systems – Performance

Implementation – Coulvert Bolts

- CORRUGATED STEEL PIPE INSTITUTE – PERFORMANCE

Ministère des Transports Québec

Infrastructure materials services

4.2 CONCLUSIONS for THE SALT SPRAY TEST

The salt spray tests showed that the least resistant coatings in the salt spray test are the following parts:
Number 13 (HDG) which gradually corroded between 830 and 4,180 hours. At 2,050 hours, it was entirely corroded. It is closely followed by **number 6 (Geomet T 321), number 11 (Magni Coated Bolts - BO6J+P126L) and number 12 (Magni Coated Bolts - BO6J + B18)**. These bolts were corroded progressively between 1,000 and 2,840 hours. After 4,200 hours, these bolts show 90% corrosion of the total coating.

An average resistance to corrosion is attributed to:
Sample **number 7 (Dacromet -ASTM F1136)**, which started corroding at 3,375 hours in salt spray. At 4,180 hours, the bolt was corroded at 20% of its surface.

Samples **number 5 (Geomet 321 - ASTM F1136) and number 10 (Magni Coated Bolts - 2 X B18 RE)** corroded between 2,840-3,840 hours. At 4,180 hours in salt spray, these samples were corroded at 40% of their surface.

Good corrosion resistance is attributed to sample **number 8 (Dacromet Plus)** where the coating is etched at 3,840 hours and the bolt begins with isolated corrosion points (diam ≤ 05 mm) at the end of the test (4,200 hours).

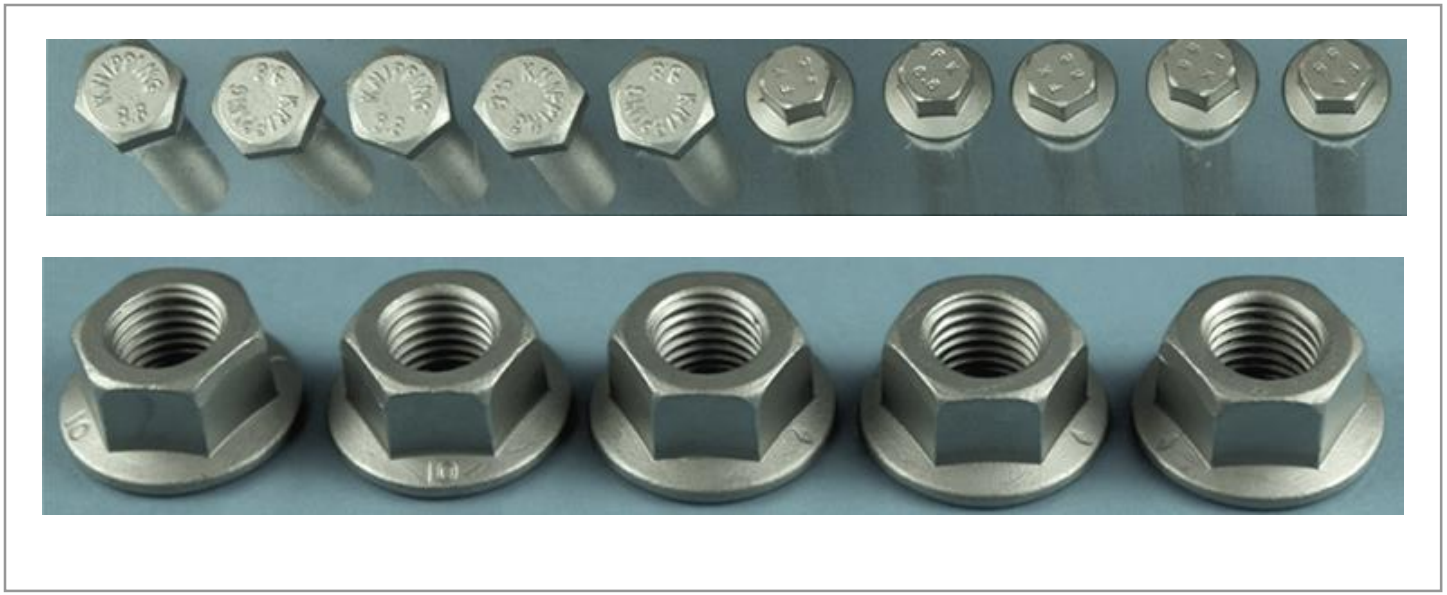
The **best resistance** to corrosion is attributed to samples **number 1 (Phos – Leland), number 2 (Undip AP – Leland) and number 4 (Undip (A) – Leland).** The coating demonstrated superior resistance to corrosion and the bolts show zero corrosion at the end of the test (4,180 hours).

The visual appearance of sample **number 9, the stainless steel** bolt without covering remained very good and the surface remained shiny.

Zinc flake coating systems – Performance

Test results corrosion resistance

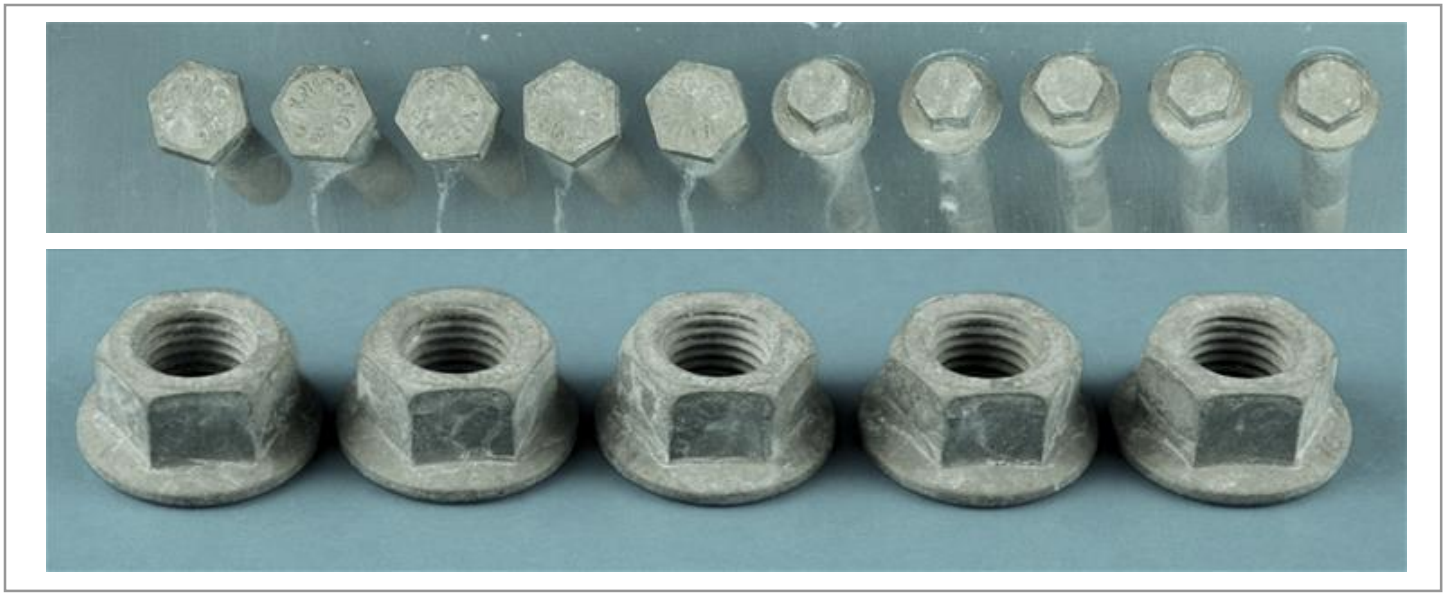
2x Zintek 200 Base Coat on screws and nuts, before NSST acc. to ISO 9227



Zinc flake coating systems – Performance

Test results corrosion resistance

2x Zintek 200 Base Coat on screws and nuts, after **1000h** in NSST acc. to ISO 9227



Zinc flake coating systems – Performance

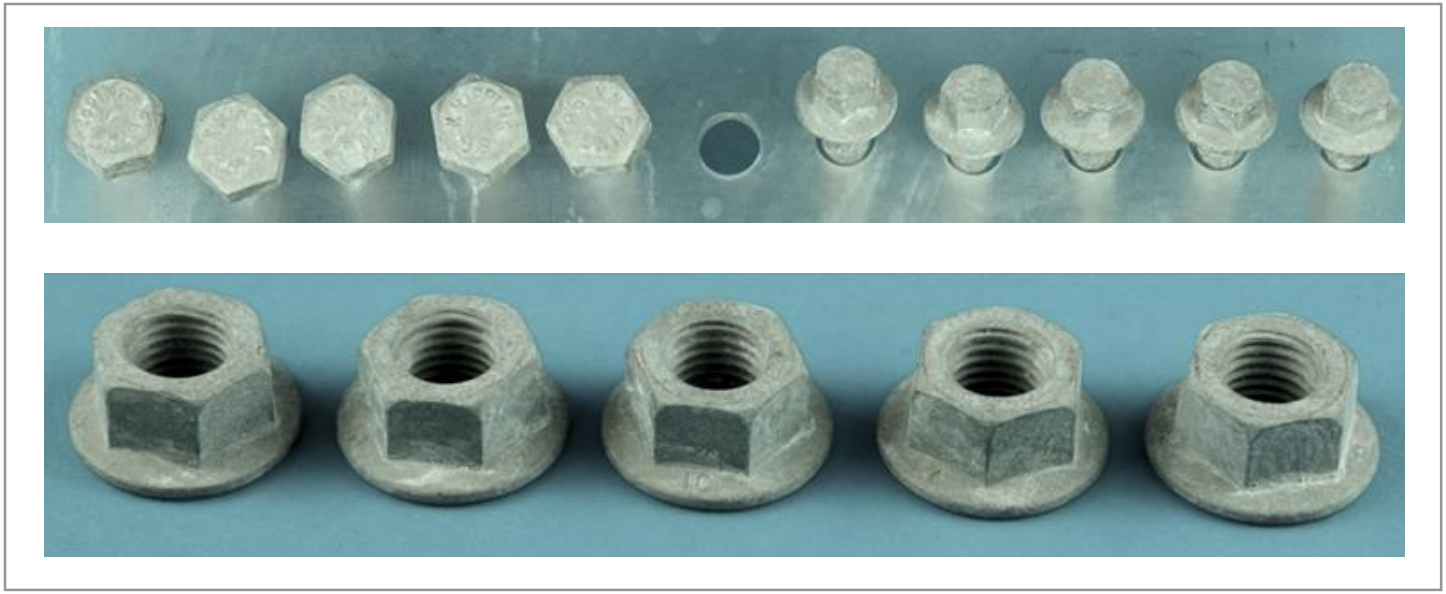
Test results corrosion resistance

2x Zintek 200 Base Coat on screws and nuts, after tempering (96h at 180°C) and before NSST acc. to ISO 9227

Zinc flake coating systems – Performance

Test results corrosion resistance

2x Zintek 200 on screws and nuts, pretreated by shot blasting, after tempering (96h at 180°C) and **1000h** in NSST acc. to ISO 9227



Zinc flake coating systems – Performance

Test results corrosion resistance

2x Zintek 200 on screws, pretreated by shot blasting, before cyclic corrosion test according VDA 621-415

Zinc flake coating systems – Performance

Test results corrosion resistance

2x Zintek 200 on screws, after **15 cycles*** in cyclic corrosion test according VDA 621-415

First red rust appeared after **16 cycles**

***At the VDA 621-415 test one cycle is equivalent to one week in the testing environment**

Zinc flake coating systems – Performance

Test results corrosion resistance

Zintek® 200

other Zinc Flake System

After impact treatment

After vibration treatment

Zinc Flake coating systems – Performance

Performance – NSS ISO 9227 - Zintek® 200 + Techseal® Silver

After 1800 hours NSST ISO 9227

After 9 cycles Volvo ACT II test

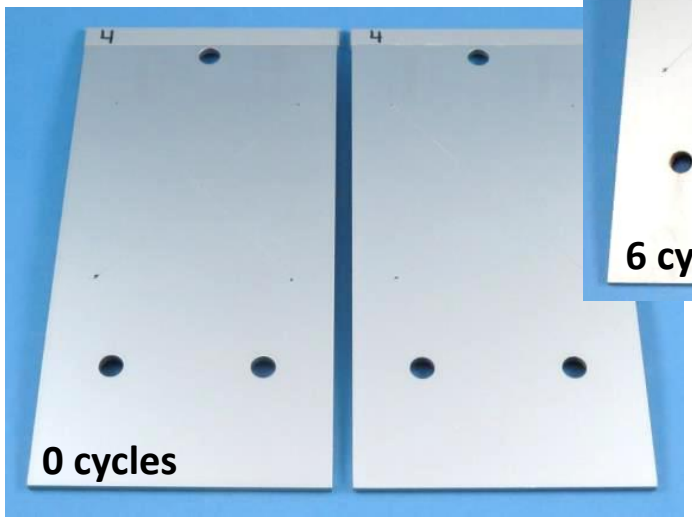
Test acc. ISO 9227

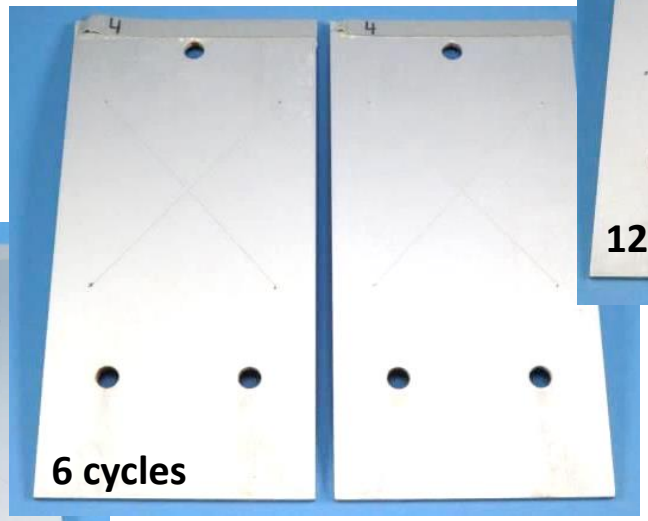
Zinc Flake coating systems – Performance

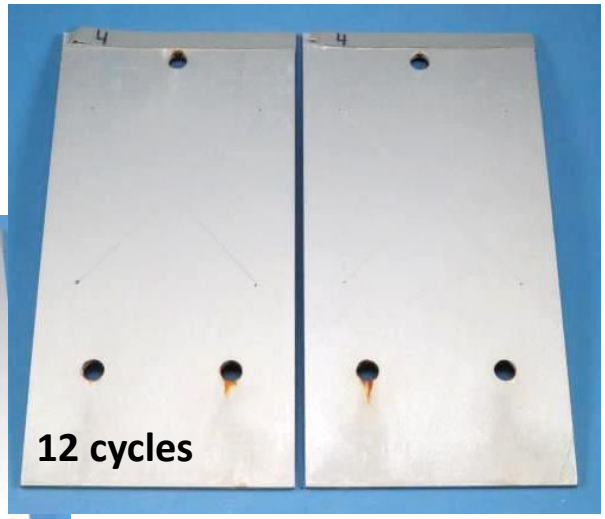
CCT (Volvo ACT II / Ford CETP 00.00-L-467) Zintek® 200 + Zintek® Top

Zintek® 200 (13µm) + Zintek® Top (1µm)

No red rust on surface!







PASSED

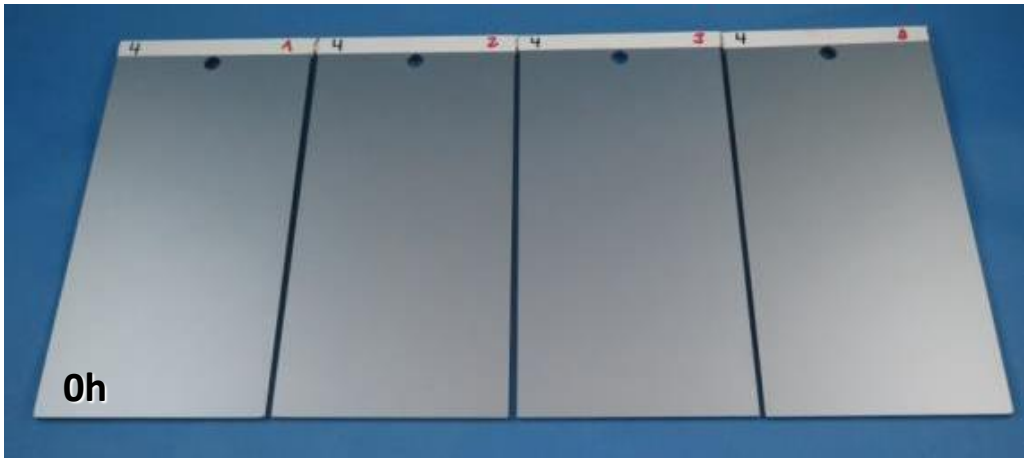
*Volvo ACT II / Ford CETP 00.00-L-467

ATOTECH

Zinc Flake coating systems – Performance

Stone chipping - Zintek® 200 + Zintek® Top

Zintek® 200 (13µm) + Zintek® Top (1µm)



PASSED

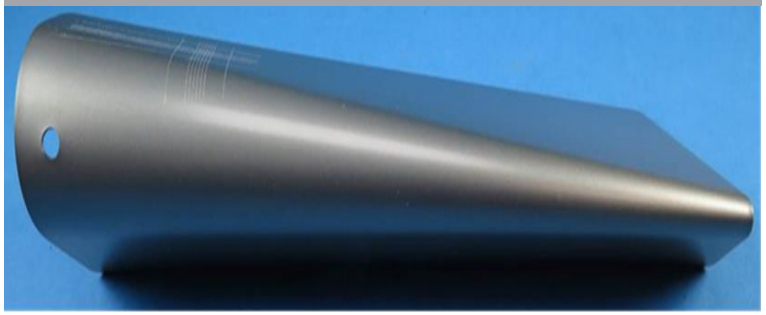
*PSA D24 1312 Stone chipping + additional NSST

Zinc Flake coating systems – Performance

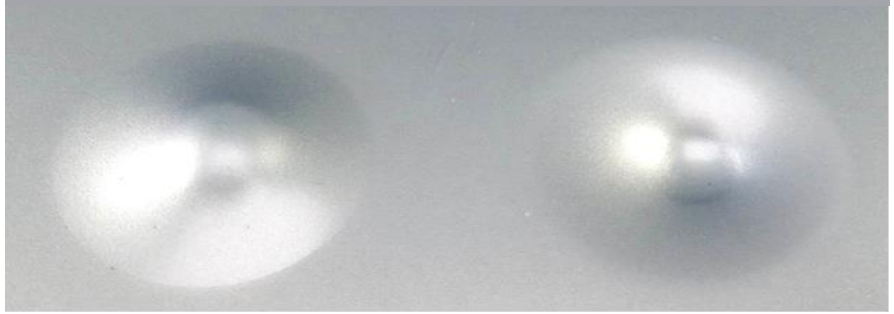
Performance – Techseal® Clear

NO FLAKE OFF

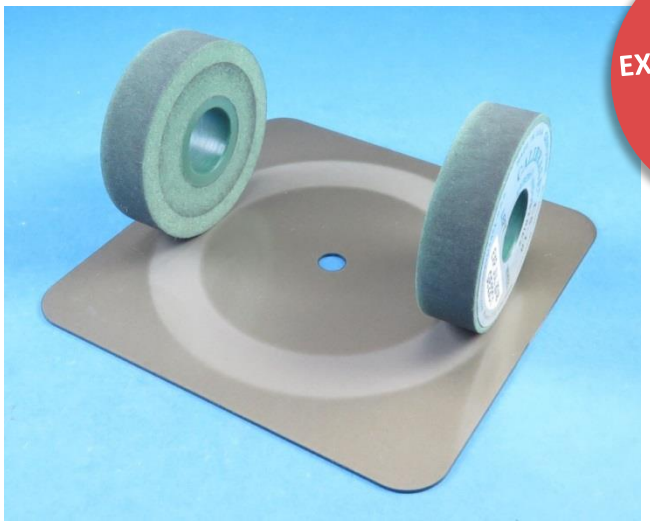
Conical mandrel test ASTM_D522



Rapid Deformation (impact) ASTM D2794



EXCELLENT WEAR RESISTANCE



ASTM D4060

Taber Abraser

The Taber Abraser is a measurement device for accelerated wear testing, by applying a specific/standardized force, simulated by rotating abrading wheels to the coating on the test specimen.

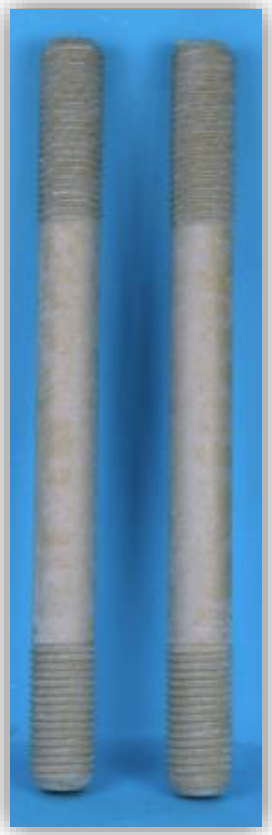
Zinc Flake coating systems – Performance

Performance of spray parts – Zintek® 200 + Techseal® Silver

0 h

1000 h

1500 h



2000 h

2500 h

3000 h

Test acc. ISO 9227

ATOTECH

SUMMARY

Zinc Flake coating systems

Summary

- Zinc flake coatings have
  - No risk of hydrogen embrittlement
  - Excellent corrosion protection
  - Competitive costs
  - No waste water

Zinc Flake Coatings

Free of heavy metals

- Atotech's zinc flake coatings:
  - Fulfil a wide range of complex industrial requirements
  - Atotech zinc flake coatings are modular making them highly versatile and adaptable for tailoring to specific requirements
  - Can also be used on a wide variety of parts in bulk as well as rack application
  - Different colors are possible by using our top coats
  - Leading protection for your components!

Co - free

Cr(VI)-free

Thank you

for your attention!

Contact

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