Fumalock®
Non-PFAS & non-fluorine fume suppressant for Cr(VI) technology

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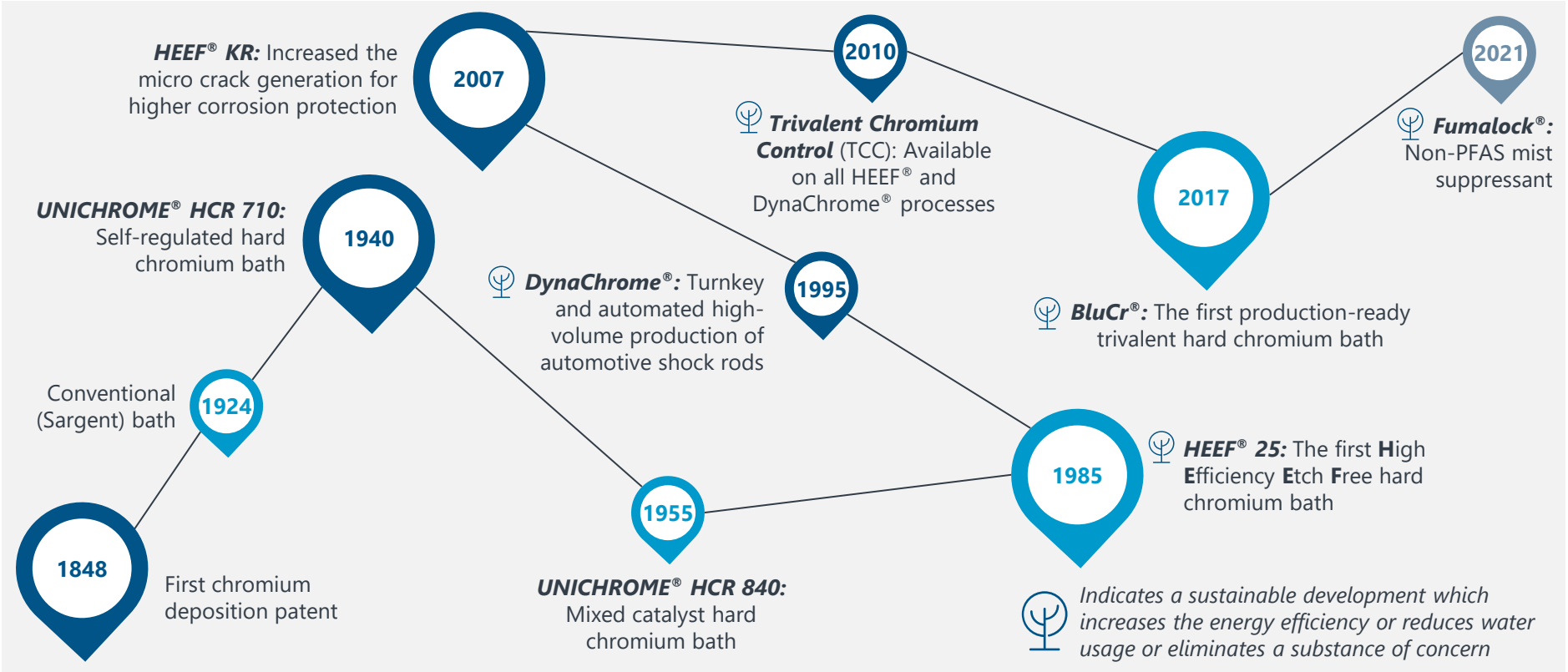
Introduction

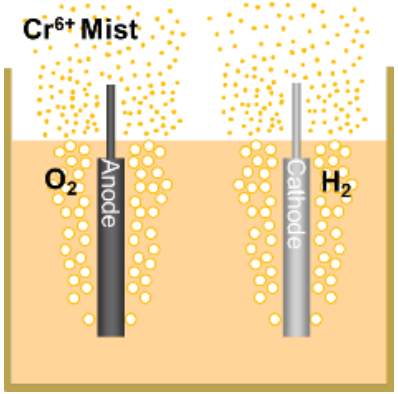
Chrome plating considerations – Mist formation



Chrome plating considerations – Mist formation

- Chrome plating suffers from low effective current efficiencies of 12% to 30%
- The majority of current mainly causes electrolysis of water resulting in formation of large amounts of H_2 and O_2 gas
- Due to the depth of plating tanks and the size of the gas bubbles, a large amount of spray or mist is generated
- With chromic acid being hazardous for workers some method is required to reduce their exposure to this spray/ mist
- One proven method is by adding mist suppressant chemistry to the plating tanks

Spray mist formation by gas formation



Cr(VI) droplet emission

Regularity status concerning PFAS

Regulatory landscape for PFAS – Europe

Highly persistent, toxic to reproduction and suspected carcinogen and endocrine disruptor

February 7, 2023: Restriction proposal on PFAS

1. **Shall not be manufactured, used or placed on the market as substance on their own,**

2. **Shall not be placed on the market in**
   a. Another substance, as a constituent,
   b. A mixture
   c. An article

   In a concentration of or above:
   i. 25 ppb for any PFAS (polymeric PFAS excluded)
   ii. 250 ppb for the sum PFAS
   iii. 50 ppm for PFAS (including polymeric PFAS)

3. **Paragraphs 1 and 2 shall apply 18 months after entry into force of the restriction.**

March 2023	March 22,2023	Q2/ 2024	2025	2025	Mid 2027
RAC and SEAC will evaluate the proposal	6 months public consultation started	ECHAs committees evaluation completion	Discussion and decision of the European commission	Restriction is expected to enter into force	18 months transition period ends

Phase out earliest mid 2025

Regulatory landscape for PFAS – Rest of the world

	2021	2022-2023	End 2024
USA	• PFAS Roadmap published by EPA • **Voluntary Stewardship program including ceasing of manufacturing** • **National Testing Strategy** • **Prohibition of PFAS release to the environment** • **Air emission reduction**	• **Authority Testing on contaminations at manufacturer sites** • Reporting rules and tracking back to 2011 • Drinking water standards for PFOS/PFOA	• Implementation of the PFAS action plan completed • State specific regulations to be implemented
China	• **PFAS** planned to be subject of restrictions in 2025 • Priority on PFHxS, PFOS and PFOA -> Ban/ restriction will enter into force January 2024		**Phase out earliest beginning 2025**
Australia and New Zealand	• Draft **PFAS** action plan similar to USA to be fully implemented by end 2024		
Rest of Asia (Thailand, South Korea, Japan, Vietnam, SEA)	• Focus on PFHxS, PFOA and PFOS in 2023 and 2024 -> **PFAS** restrictions to be drafted starting in 2025		

Process features

Benefits

New generation of fume suppressant for Cr(VI)

- Does not contain fluorine/PFAS
- No comparable process at the market available
- Patent pending

Excellent mist suppressant efficiency

- Forms a dense and thin foam blanket
- Reduces surface tension

Protective performance verified

- Complies with Cr(VI) emission limits (OSHA, NESHAP (US))
- Stack test performance comparable with F-based products

Unique process properties

- Wide operating window and adjustable foam blanket thickness
- Better resistance to hard water and excellent tolerance to metal impurities

Benefits

Fumalock® is a very effective 2-component process

FUMALOCK® A3

Foam blanket generator

Significantly reduces surface tension

A more diluted version of this product “Fumalock® A” is also available (discuss with your MKS representative for more details)

FUMALOCK® B3

Foam height controller

Slightly lowers surface tension

A more diluted version of this product “Fumalock® B” is also available (discuss with your MKS representative for more details)

Steady state operation of Fumalock®

Process operation

Make-up procedure

- Start additions:
  - 0.3 – 1.0 ml/l Fumalock® A3
  - 0.03 – 0.10 ml/l Fumalock® B3
- Perform plating test ≥5 minutes after additions of additives to assess foam level
- If foam is not covering electrolyte fully, add stepwise Fumalock® A3 until foam is even
- If excessive levels of foam blanket is produced, add stepwise the Fumalock® B3 to correct
- Can also be applied for conversion from Fumetrol®
- Moderate air agitation and/or eductors are beneficial for additive distribution
- Do not add products near heaters!

Temperature up to 60 °C	Fumalock® A3		Fumalock® B3	
	Min	Max	Min	Max
Make-up [ml/l]	0.30	1.00	0.03	0.1

The Fumalock® A3 and B3 are used 1/3rd accordingly

A minimum initial ST value < 42 dynes/cm is recommended before any plating activity

Dosing rate

Higher dosing rates during initial run-in period:

- 0.06 ml/l per h for Fumalock® A3 (adjustment ~ after 1 – 2 weeks of operation)
- 0.02 ml/l per h for Fumalock® B3

Dosing rates should be adjusted depending on parameters and conditions

After idle periods, if ST is >42 dynes/cm, a new make up amount is required, e. g. weekends, holidays, etc.

Temperature up to 60 °C	Fumalock® A3		Fumalock® B3	
	Min	Max	Min	Max
Replenishment [ml/l per h]	0.03	0.08	0.008	0.030

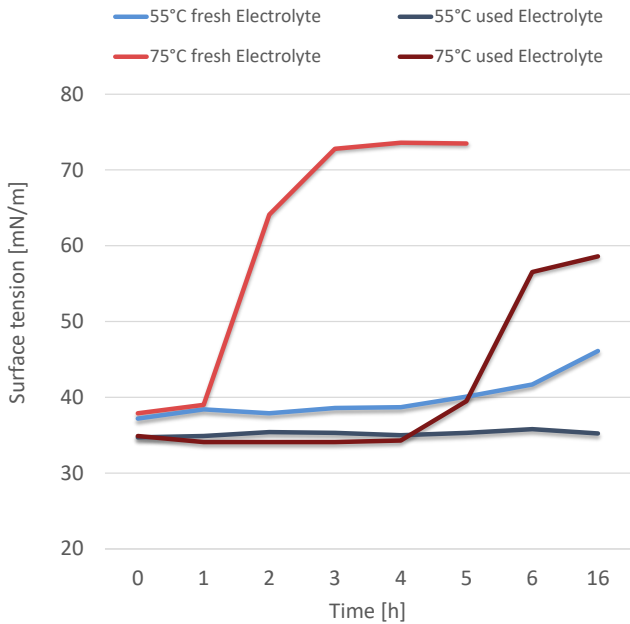
3-fold components Fumalock® A3 and B3 are consumed by 1/3rd accordingly

A minimum initial ST value < 42 dynes/cm is recommended before any plating activity

Consumption of additives

Additive consumption is driven majorly by chemical decomposition and to a minor degree by electrolytical decomposition

Strong temperature dependency!
Decomposition significantly increased >65 °C
Time based dosing is recommended



Dosing is adjusted to quality of foam blanket and maintained by:

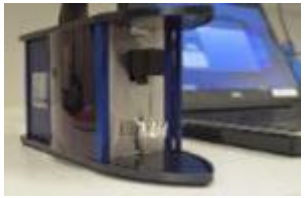
- Surface tension measurement
- Monitoring of foam height and coverage ability

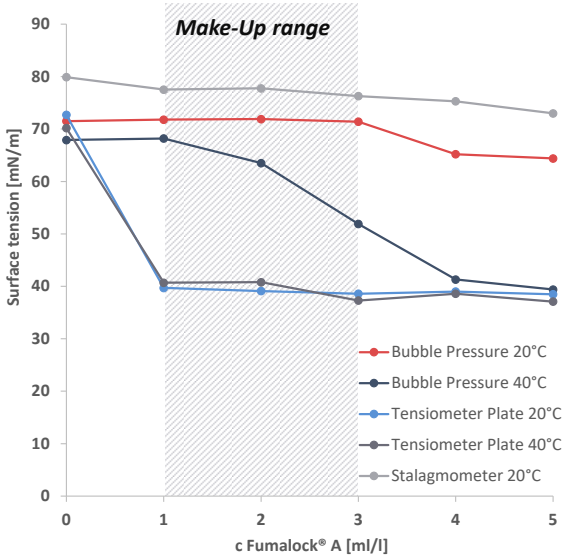
Surface tension - Measurement and control

Monitoring of the Fumalock® A3

- Surface tension is a good indicator for Fumalock® A3 content
- Not suitable for foam assessment
- ***Only static ring and plate tensiometer are recommended!***
- Allows estimation of additive level in the working bath: working range

Example Tensiometer AquaPi ™ - Portable Tensiometer (~ 7000 €)





Final ST can be lower by increasing bath age and addtion of Fumalock® B

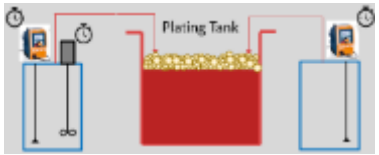
Products and dosing equipment

- Dosing system to be set-up beside the plating tank
- **FUMALOCK® A3** needs to be maintained in suspension by constant stirring
- Dosing pumps control
  - By timer (recommended)
  - 1 dosage per hour minimum
  - Preferably twice per hour
- Concentrated products (A3 and B3) need pre-mixing
- Extra additions may be required after reaching downtime

- Product is a suspension
- Dissolves in hot electrolyte
- Stir/shake prior to dosing/addition
- Concentrated Fumalock® A3 needs pre-dilution of 1:2 before addition/dosing

- Product is an emulsion
- Concentrated Fumalock® B3 needs pre-dilution of 1:2 before addition/ dosing

A or A3



B or B3

Process performance

Tested at different stages and customers

Product development stages

Beaker scale

1 – 5 l scale

Proof of concept

Emission testing

Manual pilot tank

110 l – 380 l

Dosing concept

Comparative qualification

Certified emission testing

Automated pilot line

170 l

Long-term use

Automated dosing

Certified emission testing

Customer test

0 – 26 000 l

Multiple customer tests in various regions

High customer satisfaction

Foam blanket as function of Fumalock® A

Fumalock® A	Too less (Fumalock® B present)	No (Fumalock® B present)
Coverage	No coverage in plating area	No coverage at all
Elevation	Flat foam, < 0,5 cm	No foam at all
Color	If foam than yellow to orange color	Electrolyte color, dark
Bubbles	Small bubbles, dense foam but not were needed	No bubbles

Cr(VI) emission level - results in US standard tests meet requirements

OSHA Personal Exposure Limit (PEL)

- Test performed at 36 – 40 dynes/cm

Below are the results of the industrial hygiene monitoring that were conducted during the recent EXPT 798 fume suppressant trial. Results were tested by certified laboratory using the modified OSHA ID-215 IC/UV (version 2) method and compared to the OSHA Permissible Exposure Limit (PEL-TWA) & Action Levels for Hexavalent Chromium (plating).

Hexavalent Chromium - (29CFR1910.1026)
OSHA 8-hour PEL-TWA = 5.0 ug/m3
OSHA TWA-Action Level = 2.5 ug/m3

Date	Sample ID	Product Bath Tested	Sample Time (minutes)	Test Result (ug/m3)	8-hr TWA (ug/m3)	[illegible]	8-hr TWA (at sampled exposure level)*	Below OSHA Action Level
11/16/20	RH20-067	FC-EXPT 798	90	<0.16	[illegible]	[illegible]	<0.16	YES
11/16/20	RH20-068	FC-EXPT 798	90	<0.16	<0.00	YES	<0.16	YES
11/16/20	RH20-069	FC-EXPT 798	90	0.16	0.10	YES	0.55	YES
11/16/20	RH20-070	DECO-EXPT 798	90	<0.16	<0.03	YES	<0.16	YES
11/16/20	RH20-071	DECO-EXPT 798	90	<0.16	<0.03	YES	<0.16	YES
11/16/20	RH20-072	DECO-EXPT 798	91	1.20	0.23	YES	1.20	YES
11/16/20	RH20-073	FC-EXPT 798	93	<0.16	<0.03	YES	<0.16	YES
11/16/20	RH20-074	FC-EXPT 798	93	0.34	0.07	YES	0.34	YES
11/16/20	RH20-075	FC-EXPT 798	93	0.42	0.08	YES	0.42	YES
11/16/20	RH20-076	DECO-EXPT 798	93	<0.16	<0.03	YES	<0.16	YES
11/16/20	RH20-077	DECO-EXPT 798	93	<0.16	<0.03	YES	<0.16	YES
11/16/20	RH20-078	DECO-EXPT 798	93	0.52	0.10	YES	0.52	YES

* Represents the OSHA Time Weighted Average (TWA) with no further Hexavalent Chromium (Cr+6) exposure during the 8-hour work/sampling shift.
^ Represents the OSHA Time Weighted Average (TWA) if Hexavalent Chromium (Cr+6) exposure was received for the entire 8-hour work/sampling shift.

✓OSHA

NESHAP Stack Test

- EPA Test Method 306
- Fumetrol® 21 LF2 test performed at or below 33 dynes/cm
- Fumalock® test performed at or below 38 dynes/cm

Target Analyte	Fu[illegible]	FC - EXPT 798
Hexavalent Chrome (mg/[illegible]	[illegible]17	0.0003
Hexavalent Chrome [illegible]	1.24E-05	2.39E-06

✓NESHAP

To be in line with the NESHAP our industry demonstrates compliance by a stack test to meet the following values:

For Hard applications:
0.011 mg/dscm

For any *new* source in any application: 0.006 mg/dscm

Hard water and impurity tolerance - foam appearance vs Fumetrol®

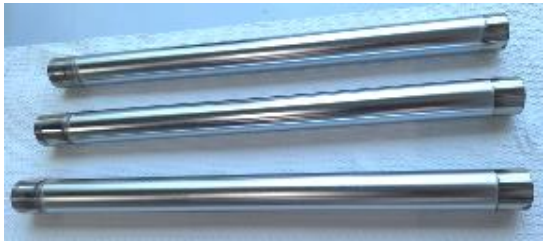
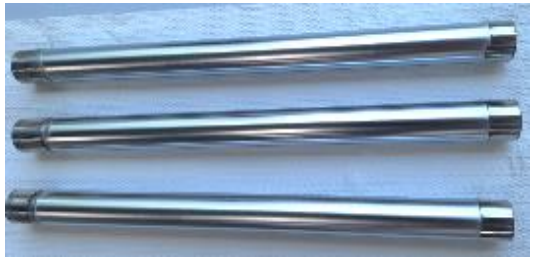
Fumalock® is insensitive against metallic impurities such as Cr(III), Cu, Ca, Na, K and Fe

Fumalock® vs Fumetrol® 21 LF2 with 10 g/l Calcium

Fumalock®	Fumetrol® 21 LF2
	

Qualification details to determine physical properties vs Fumetrol®

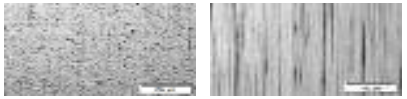
UniClean® 155	• 3 min
UniClean® 251	• 2 min • 10 ASD
Sulphuric acid (5 – 10%)	• 10 sec
Chromic acid etch	• 90 sec • 40 ASD
HEEF® 25	• 26 min • 50 ASD
Heat treatment	• 2 hrs • 200 °C
Polish	• #2000

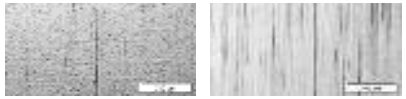
Fumalock® parts	Fumetrol® parts
	
	

Surface roughness & Micro-cracks vs Fumetrol®

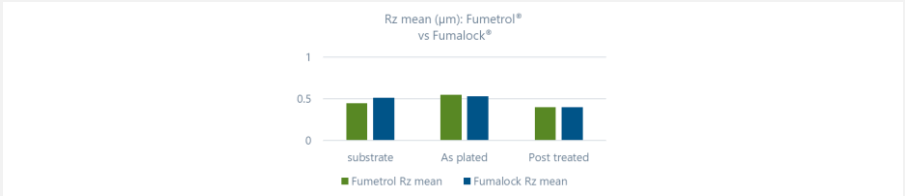
- Addition of Fumalock® does not alter surface morphology
- No negative increase in roughness compared to samples plated in the presence of reference mist suppressant Fumetrol® 21 LF 2 were observed

Fumalock®		Fumetrol ®	
As plated	Post treated	As plated	Post treated

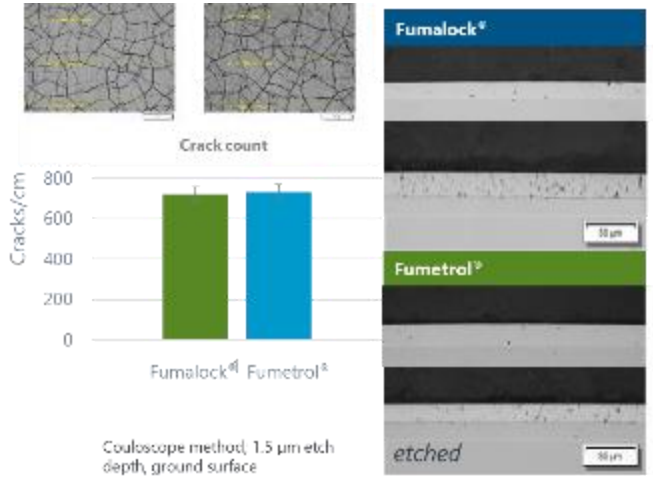




- Chromium thickness: As plated ~ Post-treated ~ 20 – 22 µm



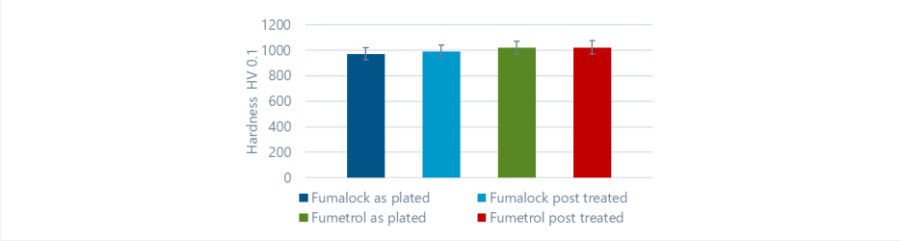
- Addition of Fumalock® does not alter crack morphology
- No negative increase or decrease of micro crack number
- No formation of macro cracks

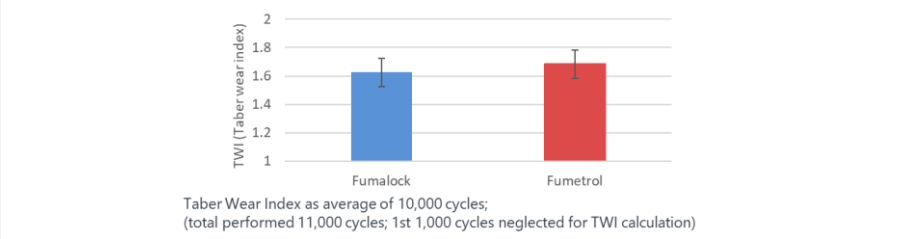


Vickers measurement and Taber Wear test vs Fumetrol®

Addition of Fumalock® does not alter hardness of final chrome deposit

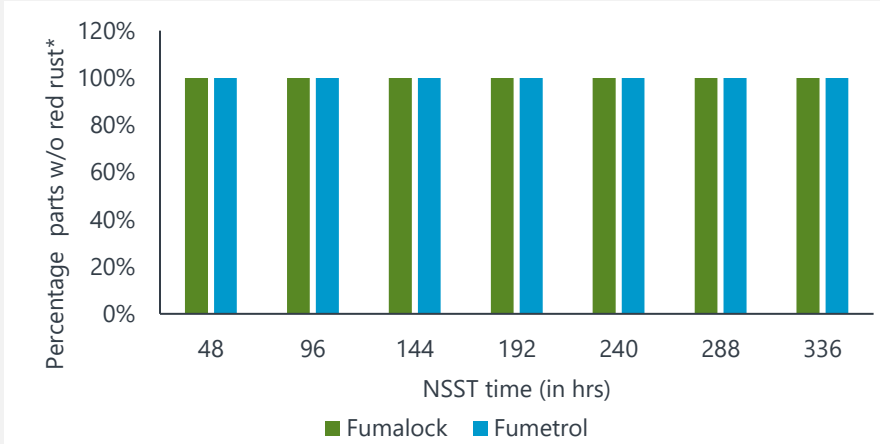
Wear resistance of chrome deposit is unaffected by the use of Fumalock®





Taber Wear Index as average of 10,000 cycles;
(total performed 11,000 cycles; 1st 1,000 cycles neglected for TWI calculation)

Addition of Fumalock® does not alter the corrosion resistance of chromium coatings!



*Parts showing red rust after 24 h were not considered as those exhibited major base material defects. 5 – 6 out of 7 tested parts were showing no red rust after 24 h. Chromium thickness ~ 20 – 22 µm

Customer case studies

Case study – Customer 1 in Germany (Shultze & Sohne)

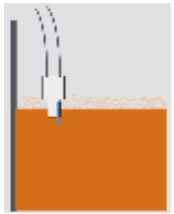
Characteristic	PFAS mist suppressant
Tank volume	1500 l
Bath agitation	Slow with pump circulation
Operating time	24 hours / 6 days a week
Dosing system	Yes (Provided by MKS Atotech)
Application	Shock absorbers (Heavy vehicles)
Operating temperature	54 – 57 °C
Foam control unit	Yes (MKS Atotech)
Surface tension measurement	Pin tensiometer (Berlin)
Emissions test results	Pass

Case study – Customer 2 in NA

Characteristic	PFAS mist suppressant
Tank volume	4000 l (Line 55) 7200 l (Line 6)
Bath agitation	Mild air & eductors
Operating time	24 hours / 6 days a week
Dosing system	Installed (Atotech system)
Application	Al motorcycle sprockets
Operating temperature	54 – 57 °C
Foam control unit	Not used
Surface tension measurement	In-house (Ring tensiometer)
Emissions test results	Passed all tests

Dosing tank Fumalock® A, A3, B3

Position of dosing tip below electrolyte and foam level!



Dosing pump Fumalock® B

Case study – Customer 3 Japanese OEM in NA

Characteristic	PFAS mist suppressant
Tank volume	Plater 1- 11,506 l Plater 2- 8,403 l Plater 3- 12,869 l Plater 4- 15,140 l
Bath agitation	Pump circulation/ eductors
Operating time	24 hours / 6 days per week
Dosing system	Using MKS Atotech system
Application	Shock absorber rods
Operating temperature	60 °C
Surface tension measurement	In-house (Ring tensiometer)
Emissions test results	New testing not required for air permit

Case study – 3 Customer for automotive in NA

Characteristic	PFAS mist suppressant
Tank volume	Plater 1- 6,056 l Plater 3- 5,678 l Plater 4- 5,678 l
Bath agitation	Pump circulation/ eductors
Operating time	24 hours / 6 days per week
Dosing system	Using MKS Atotech system
Application	Automotive/ engine Valves
Operating temperature	60 – 65 °C
Surface tension measurement	In-house (Ring tensiometer)
Emissions test results	New testing not required for air permit

Case study – 4 Customer for automotive in NA

Characteristic	PFAS mist suppressant
Tank volume	26,495 l
Bath agitation	Circulation pump
Operating time	24 hours / 7 day per week
Dosing system	Using MKS Atotech system; Only dosing Fumalock® A3
Application	Rework of heavy industrial components/ oil and Gas
Operating temperature	60 °C
Surface tension measurement	None
Emissions test results	New testing not required for air permit

Summary

Summary

PFAS material manufactures stopping supply due to litigation issues for contamination of fresh water sources, resulting sudden increase in raw material costs

Stricter legislation to ban the PFAS substances to be introduced in the coming 2 – 3 years in various countries

MKS Atotech developed the first nonPFAS fume suppressant (Fumalock®)

nonPFAS mist suppressants reduce misting associated to Cr(VI) plating by two mechanisms
Forming a **foam blanket** on the surface of the bath
Reducing the **surface tension** of the bath

Fumalock® meets the emissions requirements of the **NESHAP** and **OSHA**

Conversion to Fumalock® means no additional PFAS will be entering the system

Fumalock® is an established process in the market with many customers

Any questions?

BluCr®
Production-ready trivalent hard chromium

Shakeel Akhtar| Global Product and Business Development Manager

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Content

Process Introduction

BluCr® Field Experience – Suspension Rods

BluCr® Field Experience – Hydraulic Rods

Summary

Process Introduction

Why hard chrome at all?

Hard chrome deposits are popular due to the unique properties they imbue on standard substrates enabling them to work longer, better and under tougher conditions than they would normally survive in

Hard chrome coatings have many beneficial properties

- Very hard
- Superior tribological properties
- Chemical resistance
- Corrosion resistance

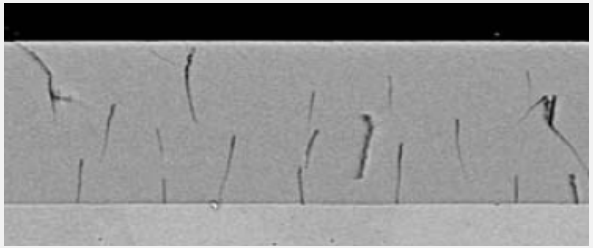
Why hard chrome at all?

Although hard chrome coatings are typically smooth and shiny in appearance, they are typically micro cracked due to a shrinking crystal structure during and shortly after plating

- High hardness of 800 – 1,100 $HV_{0.05}$
- Typical thickness 8 – 40 µm (5 – 1,000 µm)
- Micro cracked structure
- Excellent adhesion on metallic substrates

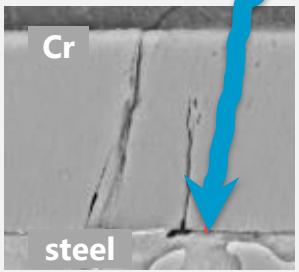
Micro-section and surface pictures after etching

Cross section of proprietary process



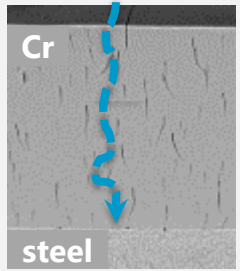
Corrosives medium

Macro cracks



Conventional process faster corrosion

Micro cracks



Proprietary process slower corrosion

Criteria for a trivalent process

Global environmental legislation, REACH in the EU, public awareness

Properties

Wear resistance

Corrosion resistance

Deposit properties

Cost effective

Trivalent hard chrome

General plating bath components	
Hexavalent	**BluCr®**
Chromic acid	Cr(III) salt
Sulfuric acid	Complexing agent
(2nd Catalyst)	Buffer
	Additives

Pb anodes

Inert anodes

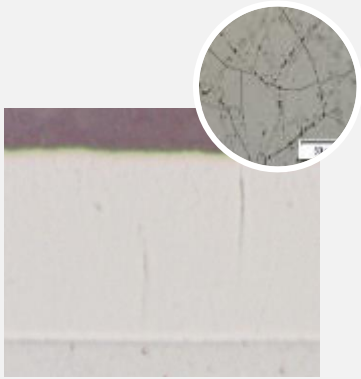
More involved bath make-up

BUT…

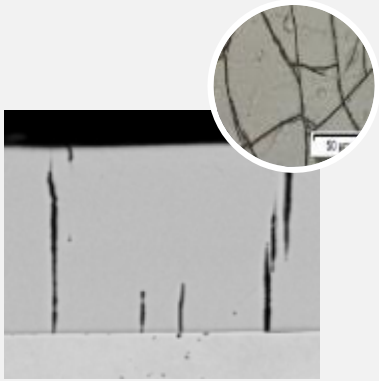
- Major reduction in hazardous substances employed
- CMR-free

Trivalent hard chrome

- Cr(III) deposit is shiny and bright
- Plated range 1 – 300 µm
- The deposit can be polished
- Similar appearance to Cr(VI) deposit
- More macro cracks



Unetched



Etched

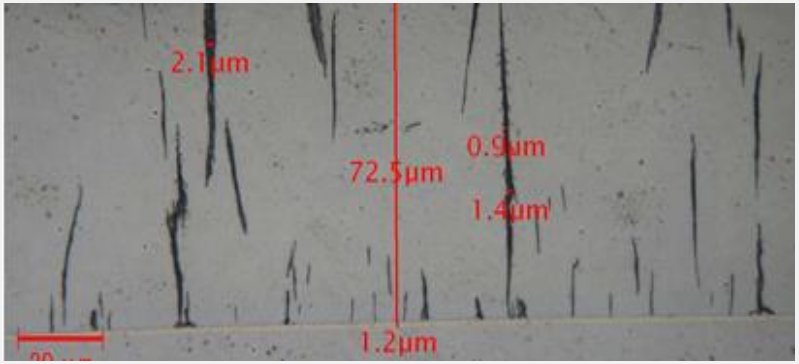
Trivalent hard chrome

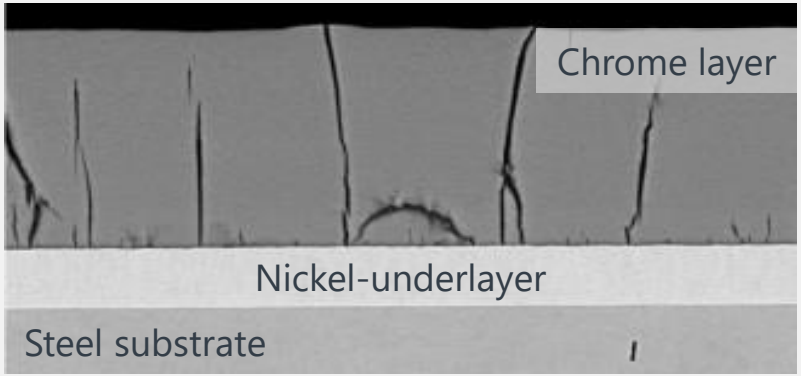
Macro cracks prevent corrosion protection

- Therefore, a dense intermediate layer is currently applied

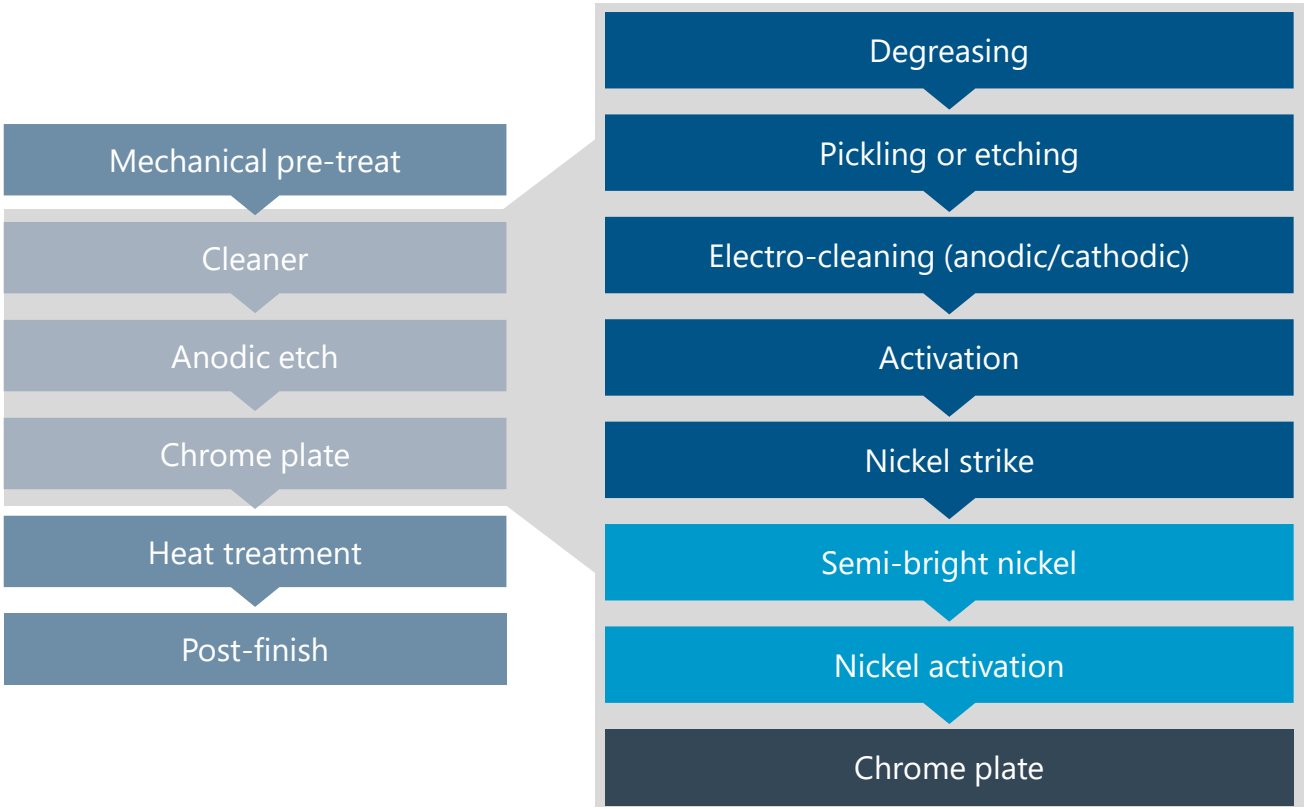
Layer of choice: Nickel

- Several hundred hours without base material corrosion can be achieved in NSST





Trivalent hard chrome

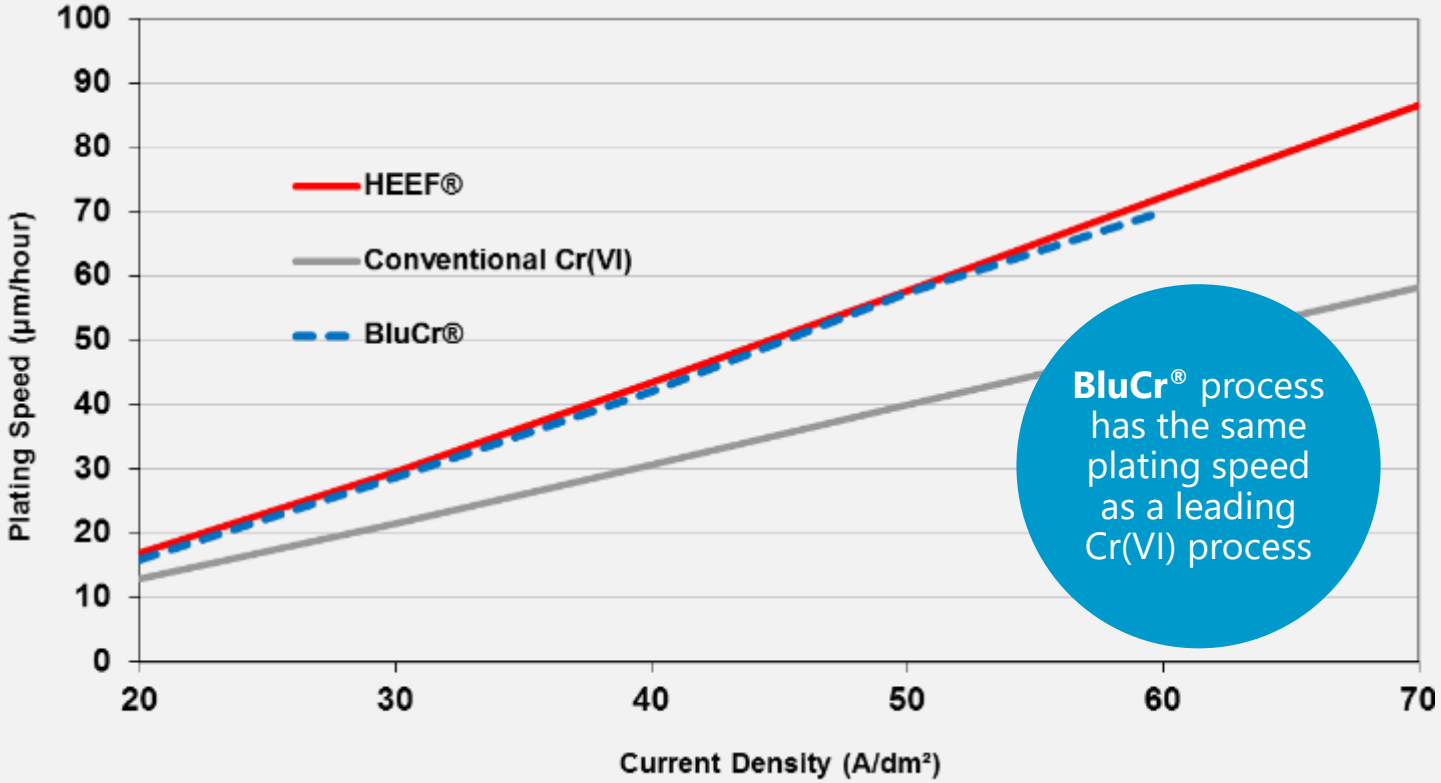


More plating steps are involved but all are **standard process** for Ni plating on steel

Challenge
Due to a long history of plating chromium directly on steel knowledge on plating an adherent and defect free nickel on steel for FC applications needs to be gained again

Each steel is different!

Trivalent hard chrome



Trivalent hard chrome

Excellent bath lifetimes achieved with good bath stability

- > 800 Ah/l
- > 200 kAh plated
- > 12 months

Good process control and long bath lifetimes possible

800 Ah/l

Excellent bath lifetime

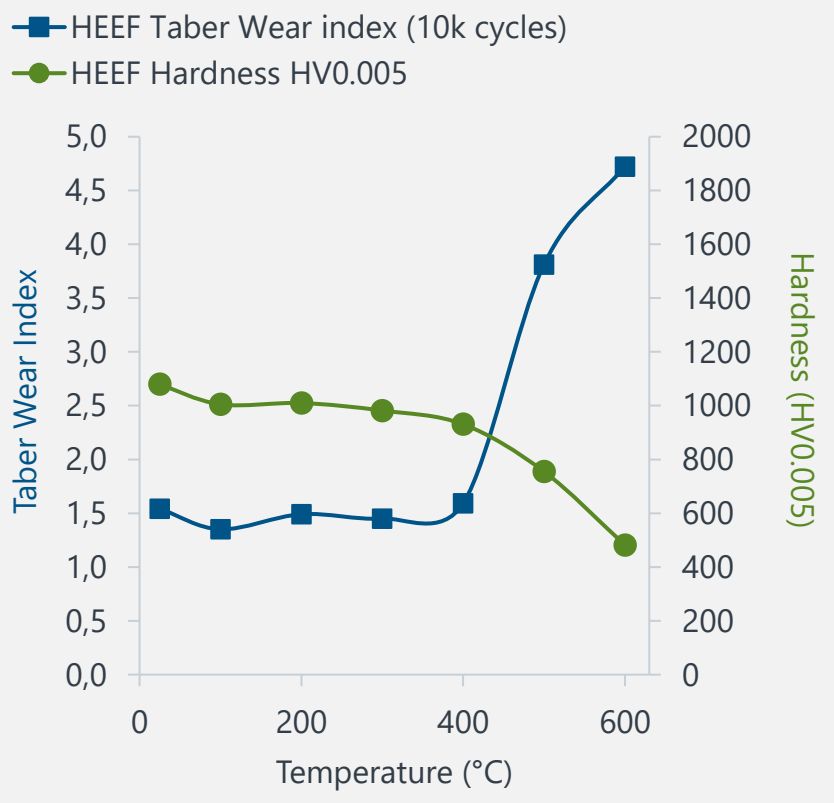
Evolution of hardness and wear with baking temperature

Hardness of HEEF® is stable until 400 °C and decreases for more elevated temperatures

Decrease in hardness in resulting in an increase of wear

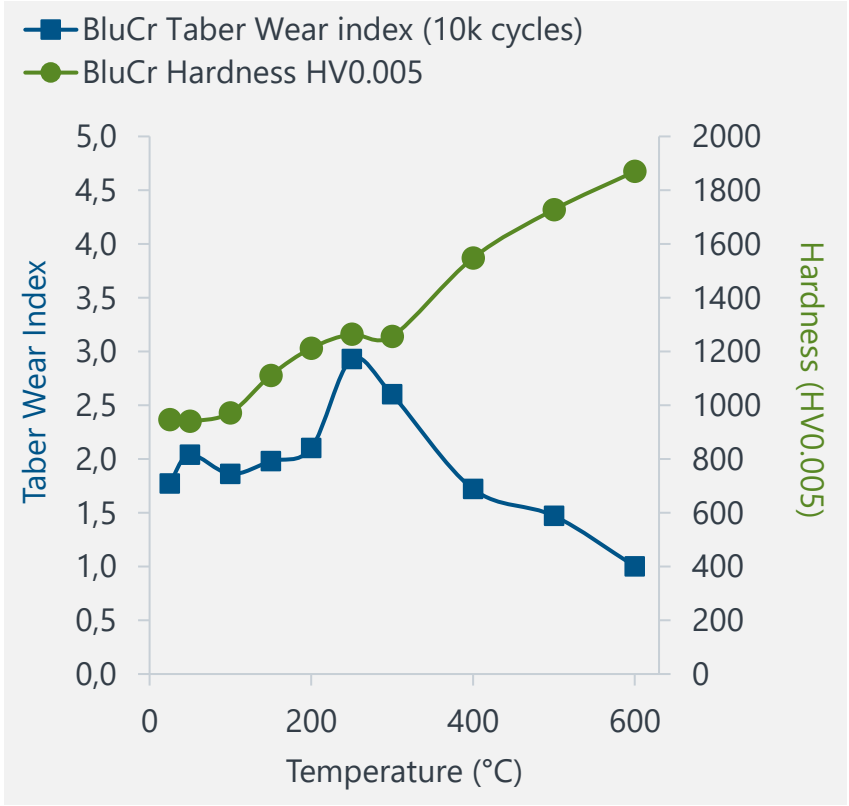
Taber wear index rises from 1.5 to 5

In cross section cracks start to become visible w/o etching at 400 – 500 °C indicating that decrease in hardness is accompanied by a volume change in the coating. But layer looks still micro cracked



Evolution of hardness and wear with baking temperature

- Hardness as plated is lower than determined for HEEF® (~100 HV) and relatively stable until ~ 100°C
- Taber Wear Index is stable at ~2 until 150 – 200 °C
- Hardness increases in 2 steps. First increases from 900 to ~1200 HV happens in the range of 150 – 300 °C
- Taber Wear Index in this temperature range reaches a maximum of 2.5 – 3.0 at 300 °C
- For temperatures in the range 400 – 600 °C hardness is constantly increasing to ~1800 HV
- Between 400 and 600 °C Taber Wear Index decreases to 1.0
- Crack width is constantly widening with increasing temperature



BluCr® field experience

Suspension rods

BluCr® trivalent hard chrome

Thickness

10 – 14 µm nickel

15 – 18 µm chrome (Cr(III))

Heat treatment

Moderate temperature 110 °C, 2 h

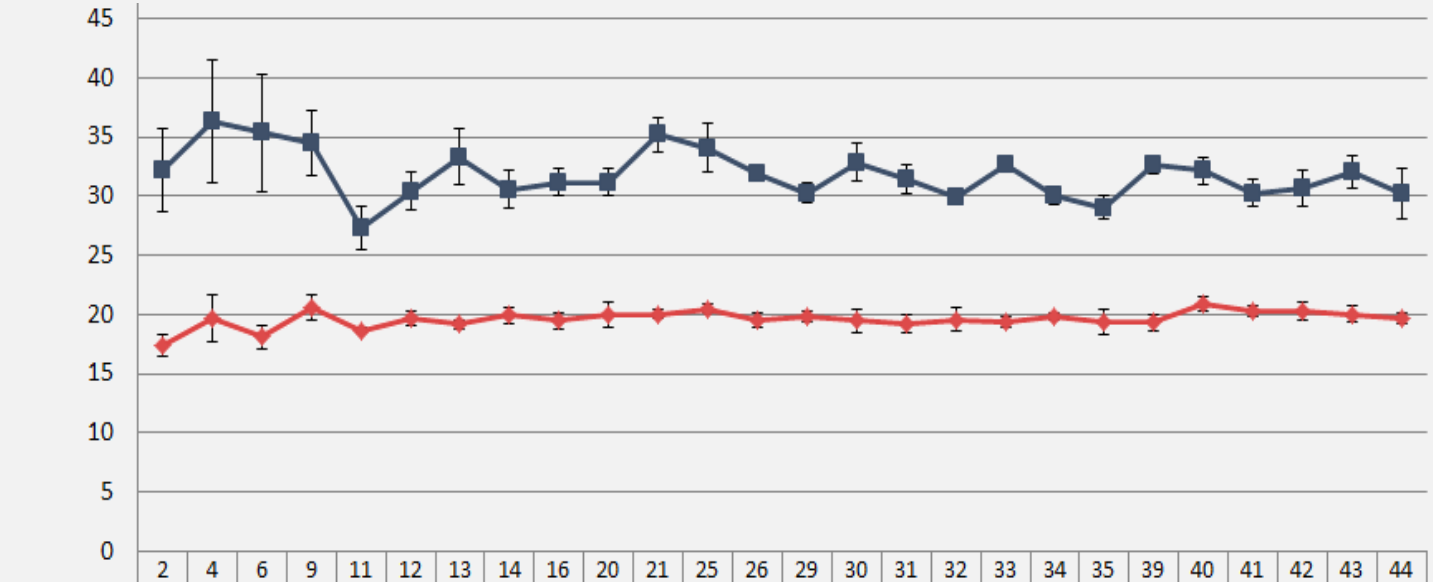
Standard temperature 220 °C, 2 h

Mechanical post-treatment

Polishing machine in TechCenter

Shock absorber plated with BluCr® (w/o post-treatment)

BluCr® trivalent hard chrome

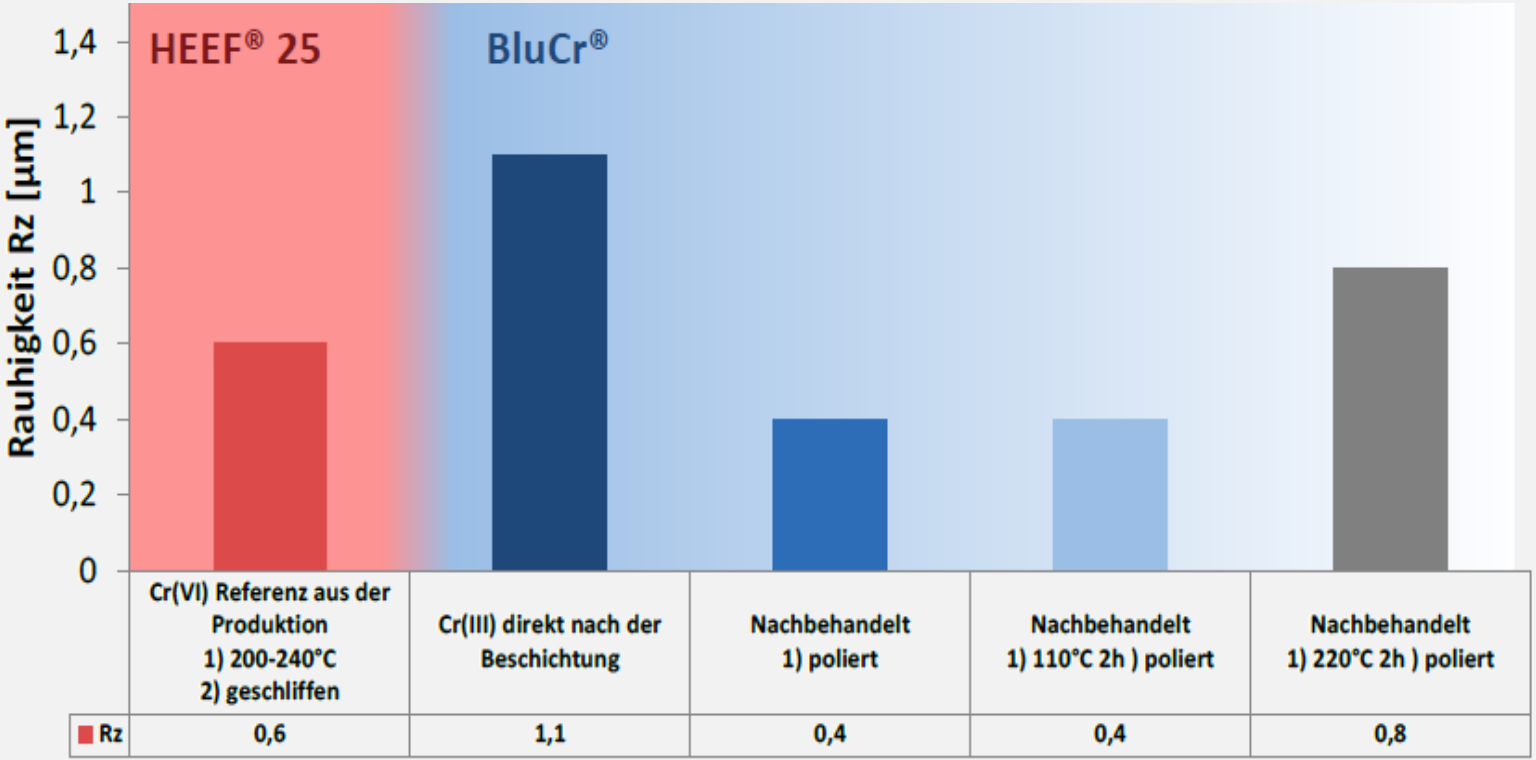


	2	4	6	9	11	12	13	14	16	20	21	25	26	29	30	31	32	33	34	35	39	40	41	42	43	44
Chromium	17	20	18	21	19	20	19	20	19	20	20	20	19	20	19	19	20	19	20	19	19	21	20	20	20	20
Total	32	36	35	34	27	30	33	31	31	31	35	34	32	30	33	31	30	33	30	29	33	32	30	31	32	30

Sample ID

Total thickness measured by micrometer screw before and after plating chromium thickness measured by Dualscope

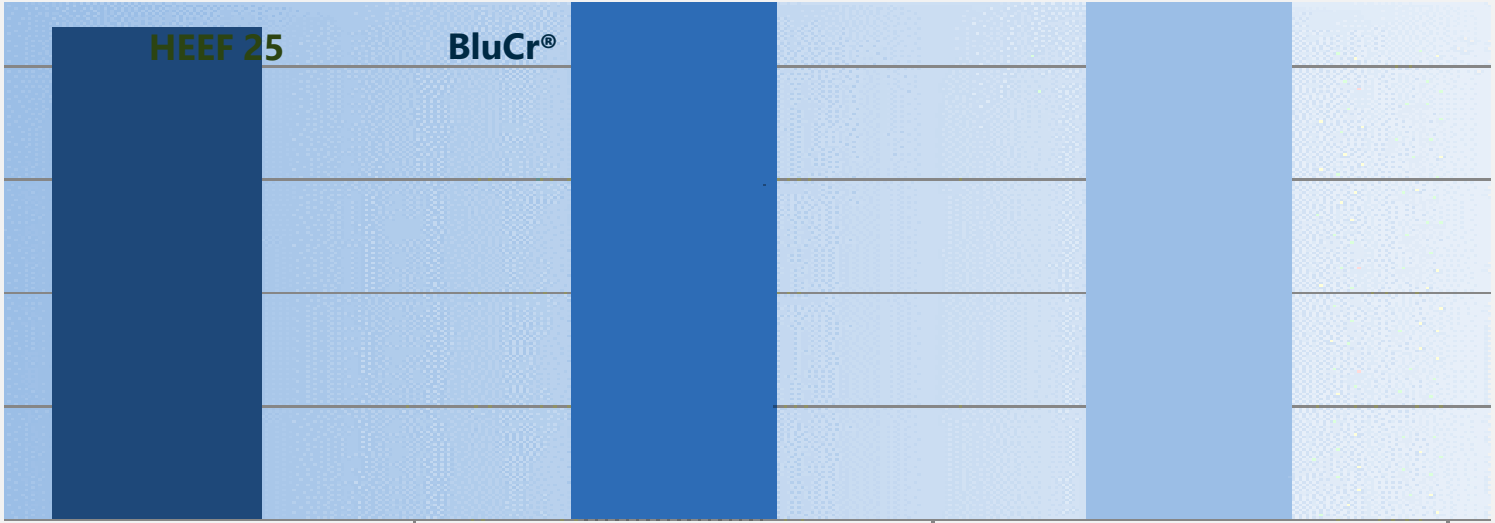
BluCr® trivalent hard chrome



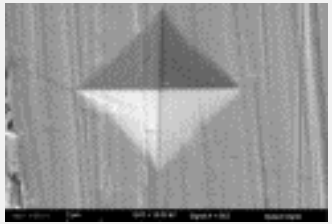
	Cr(VI) Referenz aus der Produktion 1) 200-240°C 2) geschliffen	Cr(III) direkt nach der Beschichtung	Nachbehandelt 1) poliert	Nachbehandelt 1) 110°C 2h) poliert	Nachbehandelt 1) 220°C 2h) poliert
Rz	0,6	1,1	0,4	0,4	0,8

* Polishing done at TechCenter

BluCr® trivalent hard chrome

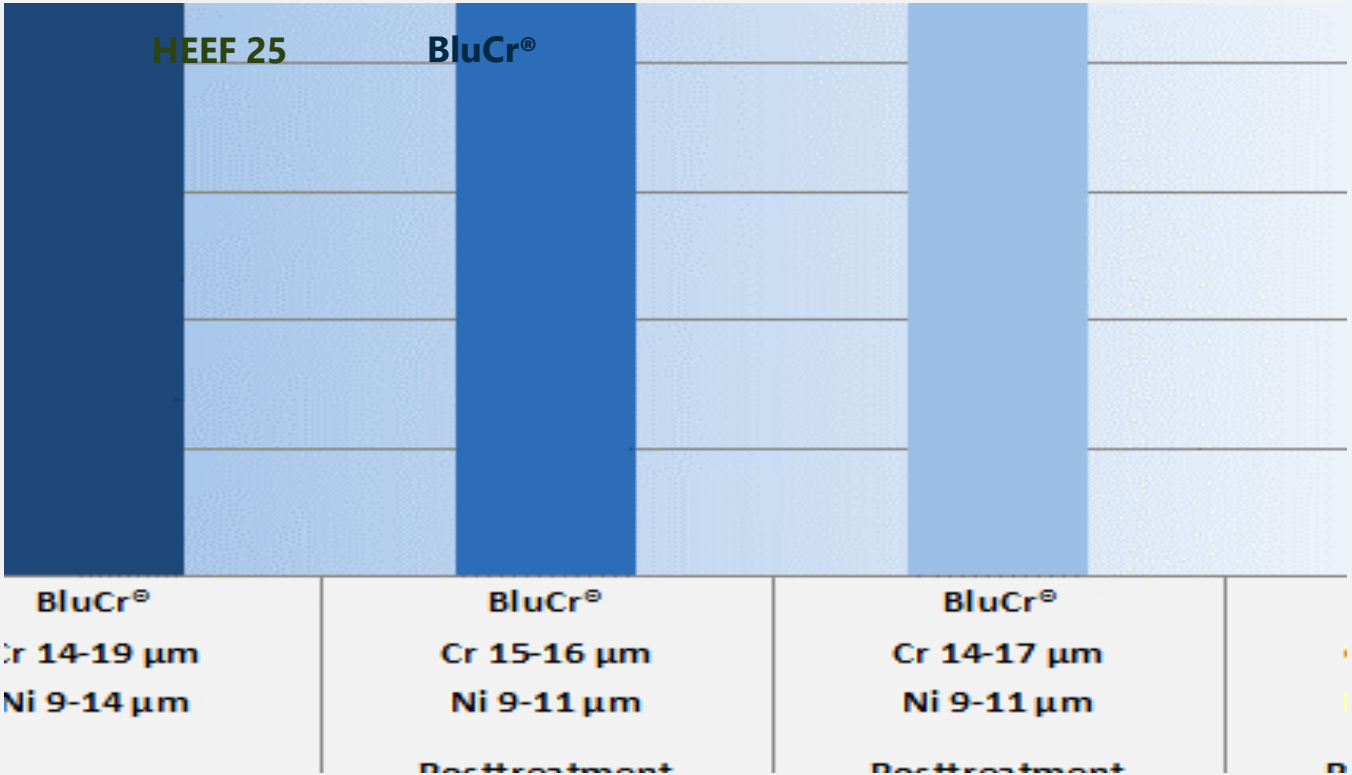


ıo Posttreatment	Posttreatment 1) polished*	Posttreatment 1) 110°C 2) polished*	
867	932	950	



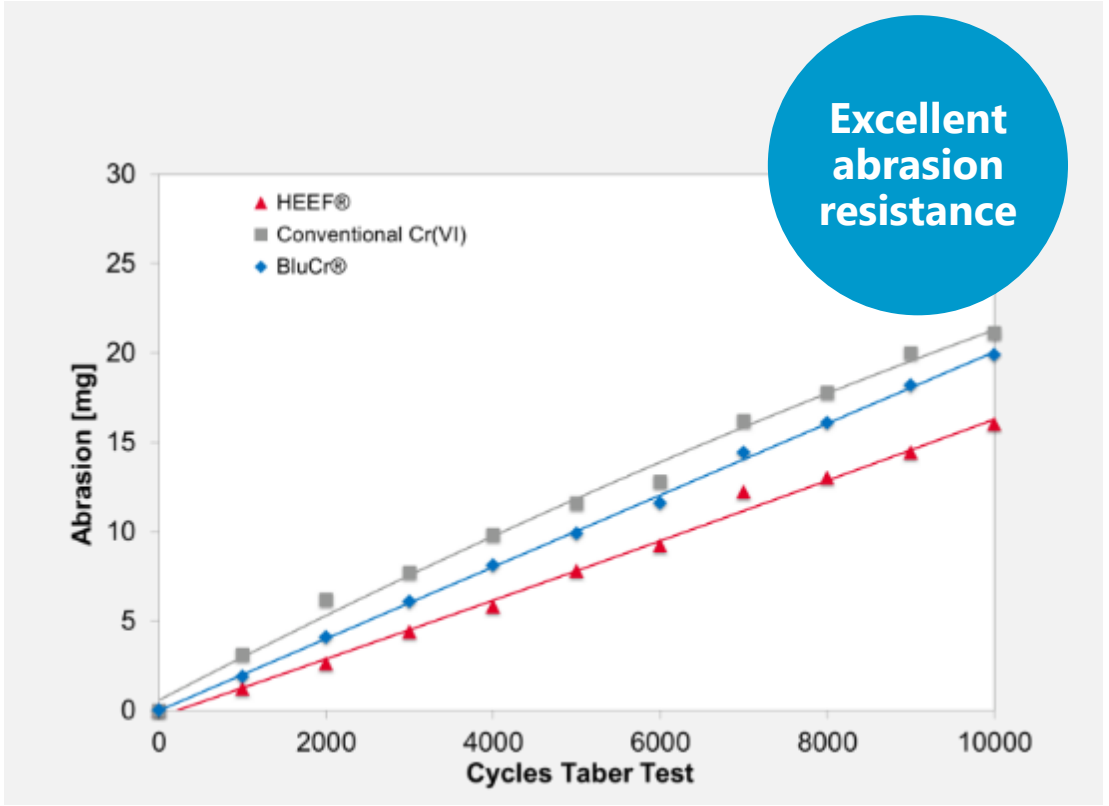
Vickers hardness indenter

BluCr® trivalent hard chrome



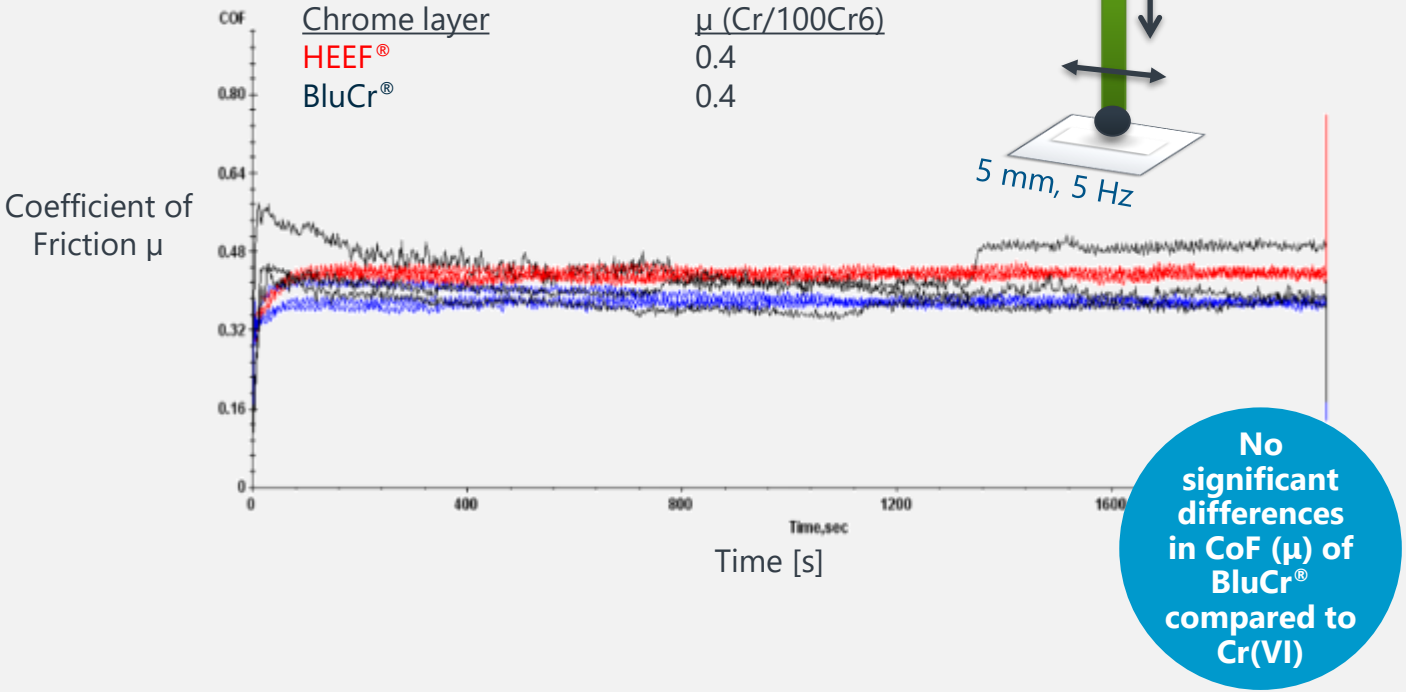
BluCr® trivalent hard chrome

Abrasion resistance of functional BluCr® layers is between that of deposits from conventional and HEEF® electrolytes



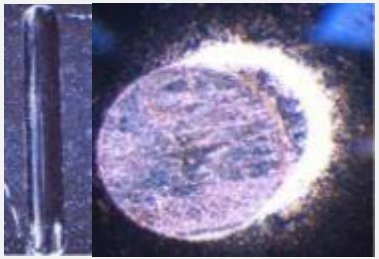
BluCr® trivalent hard chrome

Chrome layer	μ (Cr/100Cr6)
HEEF®	0.4
BluCr®	0.4

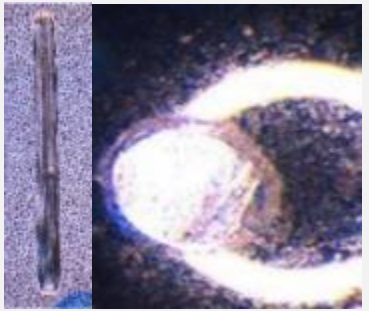


No significant differences in CoF (μ) of BluCr® compared to Cr(VI)

Cr (ball) 100Cr6



HEEF® layer



BluCr® layer

BluCr® trivalent hard chrome

BluCr® deposit contains a small amount of carbon. This imbues the coating with better chloride resistance compared to Cr(VI) deposits

Combined with the nickel underlayer it gives the whole coating a completely better class of corrosion resistance

HEEF® 25 10 – 12 µm Ni 30 – 35 µm Cr	BluCr® 10 – 12 µm Ni 30 – 35 µm Cr	BluCr® 10 – 12 µm Ni 30 – 35 µm Cr	BluCr® 10 – 12 µm Ni 30 – 35 µm Cr
			

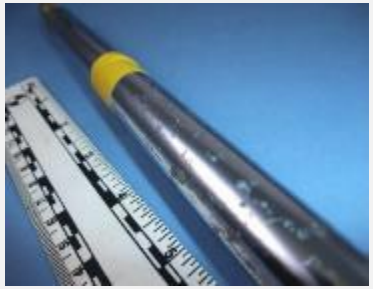
As plated nickel/chromium deposits after 240 h calcium chloride testing (60 °C, 23 RH, 1,000 g/l $CaCl_2$)

BluCr® trivalent hard chrome

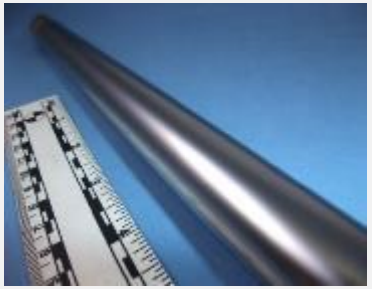
BluCr® plated shock rods tested in Russian Mud for 96 h

Customer specification for 96 h

Inspection every 24 h



Cr(VI), after 96 h, rating k3



BluCr®, after 96 h, rating o10

$CaCl_2$ solution 720 g/l
Mix 30g of kolin to $CaCl_2$ solution
Test condition 60 °C,
3 – 8% of humidity, 96 h

Rating / Area of defects			
10	0%		
9	> 0 % - 0,1 %	4	> 2,5 % - 5,0 %
8	> 0,1 % - 0,25 %	3	> 5,0 % - 10 %
7	> 0,25 % - 0,5 %	2	> 10 % - 25 %
6	> 0,5 % - 1,0 %	1	> 25 % - 50 %
5	> 1,0 % - 2,5 %	0	> 50 %

BluCr® field experience

Hydraulic rods

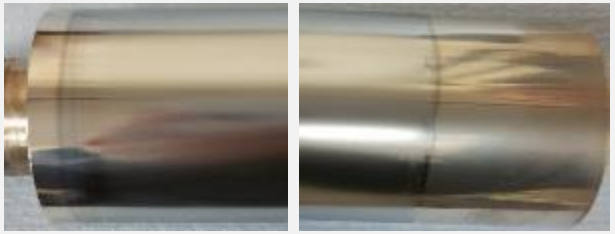
BluCr® trivalent hard chrome

- Production line for 3 m long bars
- Tanks:
  - 1 spray rinse for all steps
  - Degrease (anodic UniClean® 250)
  - Nickel (Watts Nickel)
  - Activation (UniClean® 675)
  - Sulfuric acid 20%, anodic
  - Chrome(III)
- Anodes in chrome:
  - Graphite with shielding (1/4 open)
  - Anode surface 42 dm^2

BluCr® trivalent hard chrome

Post finishing process:

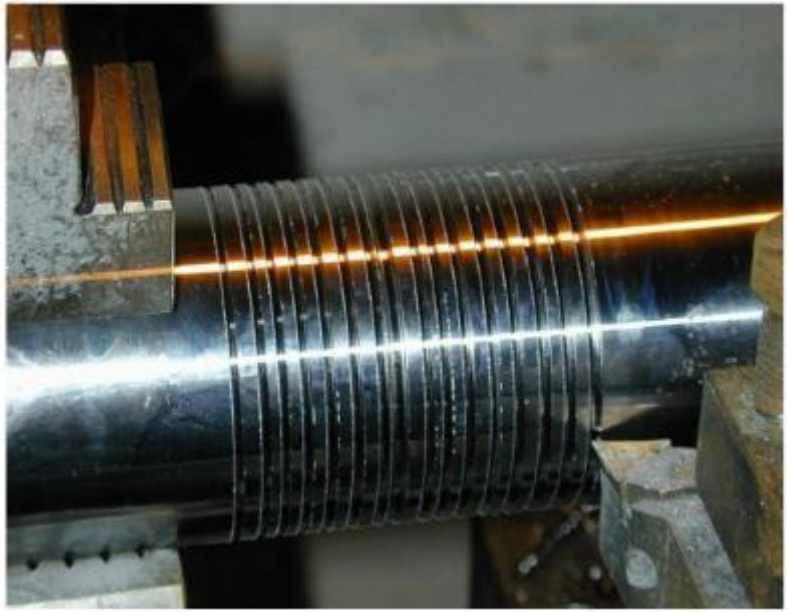
- Post-grinding
  - 3M “Trizact” belt “A6” = P2000 grade
  - 1,500 rpm
  - Applied 2 – 4 times (alternate directions)
- Buffing
  - Felt belt
  - 3,000 rpm
  - Green standard buffing paste
  - Applied 4 – 6 times (alternate directions)

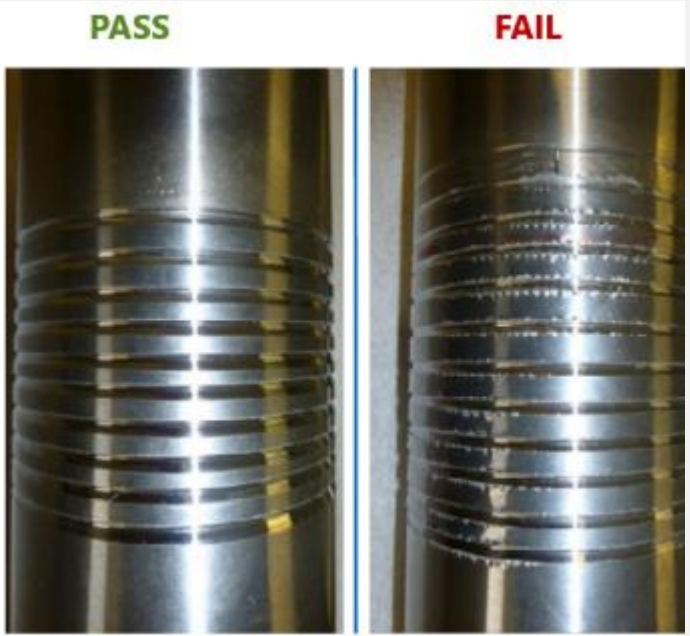


After plating

After post-finishing

BluCr® trivalent hard chrome





This is a site-specific and tougher than conventional adhesion test
We simulate the turning of the rod, because adhesion issues occur at this stage most of the time

BluCr® trivalent hard chrome

Results of BluCr® plated rods

GOOD GOOD

BluCr® trivalent hard chrome

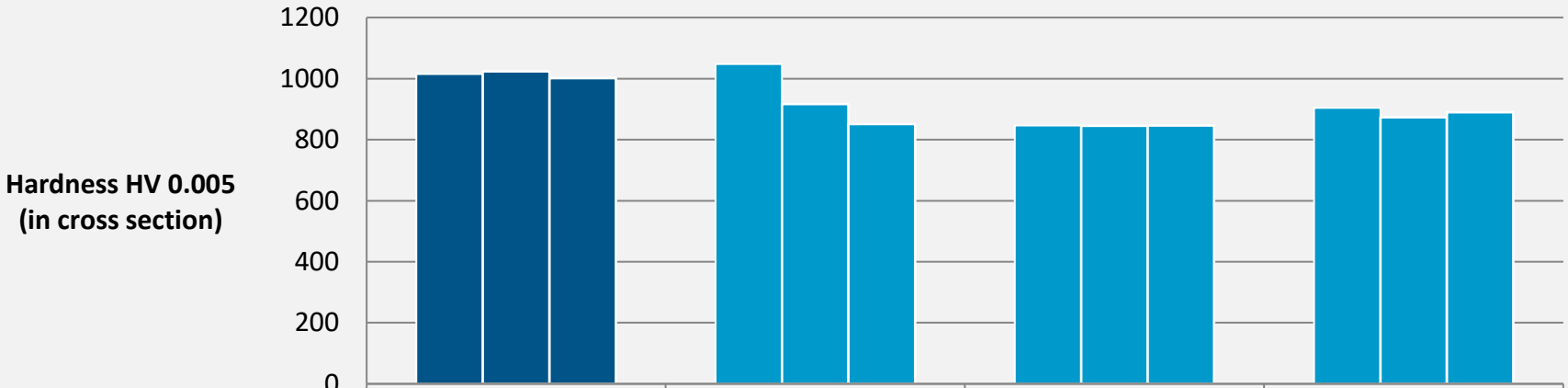
Saline Droplet Test:

- Objective = simulate behavior in marine environment with wet and dry cycles
  - Manual spray of corrosive solution on vertical bars then drying at room atmosphere
  - 1 spray per day, 5 days per week
  - Corrosive solution = real sea water, it simulates behavior in sea splash zone
  - Measure the time when the chrome layer starts to degrade without having red rust (chrome surface is attacked and black chrome oxide spots appear)

No degradation of the chrome layers after 30 days, compared to Cr(VI)

BluCr® trivalent hard chrome

Hardness was measured in cross section



	Hex. Chrome sample #0	BluCr® sample #15 post finsihed	BluCr® sample #17 post finished	BluCr® sample #27 after plating
Top (6cm from top)	1015	1048	846	904
Middle (18cm from bottom)	1024	917	845	873
Bottom (6cm from bottom)	1002	851	846	890

Post finish = grinding and buffing

BluCr® trivalent hard chrome
Field experience: Hydraulic rods

Results of monitoring at customer sites

Location	Salt factory
Condition	Severe for corrosion
Machine	Bulldozer

2 years

Location	River side
Condition	Severe for abrasion
Machine	Power shovel

10 months

BluCr®

Summary

BluCr® trivalent hard chrome

BluCr® is the first Cr(III)-based

hard chrome process in the market

- Fulfills all key requirements for hard chrome
- Stable and offers a long lifetime
- Offers better corrosion resistance compared to Cr(VI) processes
- Includes more process steps and requires more involvement than current Cr(VI) processes
- Has already been used under industrial conditions

BluCr® trivalent hard chrome

BluCr® is available for customer sampling in a local TechCenter

We are looking forward to welcoming you for plating trials at our TechCenter in Rock Hill, South Carolina

BluCr® line in TechCenter Rock Hill, South Carolina

Thank you!

Atotech GMF Seminar Poland 2023
September 19 – 21, 2023
Janów Podlaski Castle, Poland