Experience on Cadmium Replacement at Saab Aerospace

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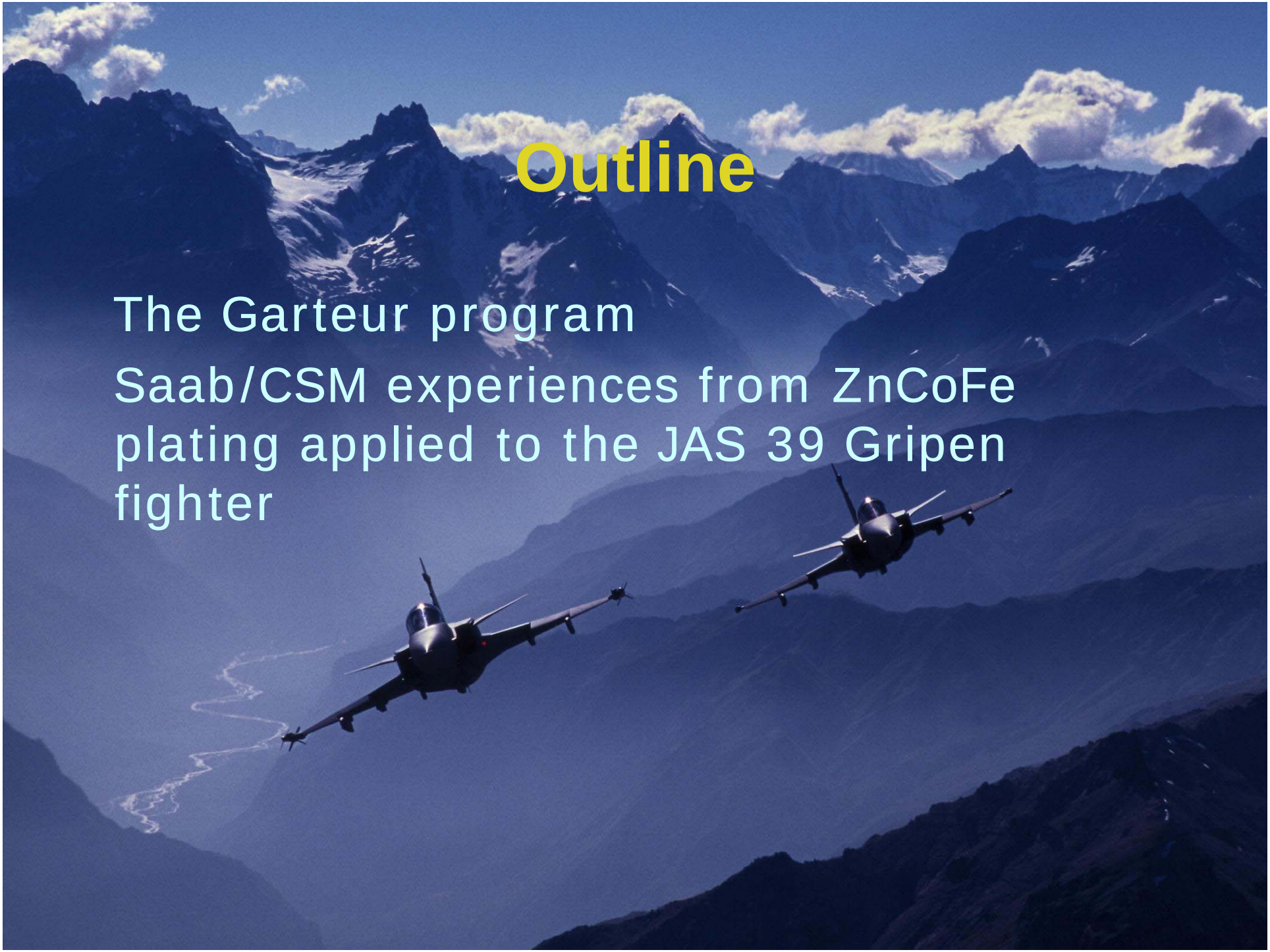

Outline

The Garteur program

Saab/CSM experiences from ZnCoFe plating applied to the JAS 39 Gripen fighter

Saab in brief

	2004	2003
Sales	17 848 (2 550)	17 250 (2464)
Operating income	1 567 (224)	1 293 (185)
Operating margin (%)	9,3	7,5
Number of employees	11 939	13 316

2004 figures

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A history of high technology

1941. First B17 is delivered

1948. ”The Barrel” – first flight

1979. First order for RBS 15

1983. Saab 340 – first flight

1993. First Gripen is delivered

2003. First delivery to A380

1937. Saab Is founded

1946. First Saab car

1969. Saab Scania is founded

1990. Saab Automobile is founded

1930 1940 1950 1960 1970 1980 1990 2000

1600 1700 1800 1900

1646. Bofors Järnbruk is founded

1894. Alfred Nobel acquire Bofors

1939–45. Bofors cannons defend London

1948.First order for Carl-Gustaf

1977. The world´s first laser-guided missile

1986.First order for AT4

1993.First order for Bamse

2000. Saab acquire Celsius

1998. StriC operational

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Saab Aerospace

- JAS 39 Gripen
  - Backbone of Swedish national defense
  - BAE SYSTEMS joint-venture for export
  - South Africa first export order (28 a/c)
- New aerospace systems, fighters, helicopters, UACV etc.
- Revenue/risk sharing Airbus programs
- Subassemblies and components for commercial aircraft

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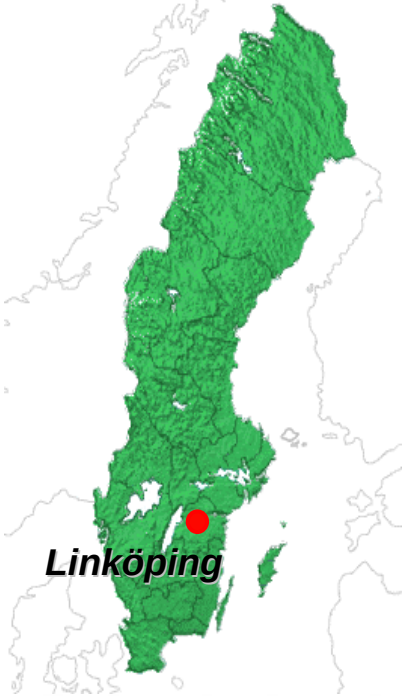
CSM Materialteknik offers materials technology solutions for every stage of a products lifecycle, from development and design to maintenance/production and recycling

We perform consultation and testing services within materials and process technology

CSM Materialteknik is the leader in the Nordic countries in advanced materials technology



Company facts

No of employees: 110

Turn over 2004: 107 MSEK (11,8 MEURO)

Owner: Saab AB 100%

www.csm.se

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Areas of activity

Metals
Polymers
Composites

Fuel
Lubricants
Chemical analysis

Surface engineering
Environment engineering

Manufacturing processes
Materials testing lab

Non destructive testing

Training

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Cd replacement

The Garteur project was used to elect a coating/coatings to replace Cd.

- Screening and introduction
- Acid ZnNi (Corroban®) was the prime candidate
- Identify coating processes as close to a drop-in process as possible
- As small changes as possible
  - Tolerances – drawings
  - Sacrificial corrosion performance
- Acceptable physical properties
- Low cost
- Environmentally benign

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Cadmium replacement program

Project partners (the work was carried out in the 90's)

- DERA, Farnborough, UK
- Shorts Brothers, UK
- BAe Systems, UK
- Saab, Sweden
- Aerospatiale, France
- Daimler Benz Aerospace Airbus, Germany
- NLR, Netherlands
- Fokker, Netherlands

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Coating material

Coating	Coating designation	Application method
ZnCoFe	Zincrolyte NCF CF	Electrodeposition
ZnNi	Corroban®	Electrodeposition
Al particles in inorganic matrix	SermeTel CR984/985	Spray
Al particles and Zn flakes in inorganic matrix	Delta-tone + Delta-seal	Electrostatic spray, dipping or spin coating
Al	Galvano-Aluminium	Electrodeposition from organic bath
Al	Ivadizer IVD-Al	PVD
Al-Mg (Mg≤10%)	Experimental coatings DERA/Salford University	PVD (unbalanced magentron sputtering)
Cd	Def STD 03-19/2	Electrodeposition

ZnNi, ZnCoFe and Cd were tested with and without passivation

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Substrates

- AISI 4130 steel
  - Panels 150 mm × 100 mm × 1 mm (approx 6” × 4” × 40 mil)
  - Fasteners
  - Fatigue strength and hydrogen embrittlement samples from rods

Corrosion Tests

- Salt spray – ASTM B 177
- Electrochemical measurements
- Outdoor exposure
- Humidity
- Boiling water exposure

Corrosion Performance

Corrosion testing

Comparing ZnCoFe, Cd, ZnNi, Al, Sermetel, Magnicoat

- Salt spray ASTM B117
  - ZnCoFe equal or almost equal to Cd and ZnNi
  - ZnCoFe and ZnNi more voluminous corrosion products than Cd, less than Zn
- Kesternich Test (w SO_2)
  - ZnCoFe superior to ZnNi and Cd

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Corrosion Results in essence

- Zn alloys and Zn based metallic-ceramic coatings behaved similar to Cd
- Al based coatings were better as barrier coatings
- Zn containing coatings and Cd exhibited superior sacrificial properties

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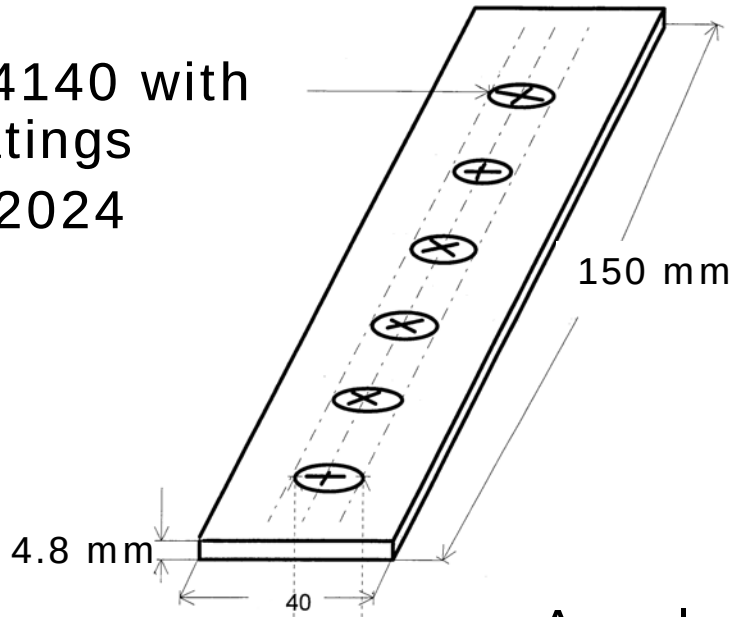
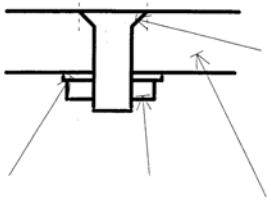
Galvanic Compatibility

Bolts AISI 4140 with various coatings

Al plate AA2024



Angular mismatch of 2º to create crevice



Al plate AA2024

Al washer

Steel nut

Galvanic Compatibility

Comparing ZnCoFe, Cd, ZnNi, Al, Sermetel

- 3 year outdoor exposure at a marine testing station to test sacrificial properties
  - Al-sheet and coated fasteners
    - ZnCoFe and ZnNi outperforms all other coatings
  - Steel sheet and coated fasteners
    - Passivated ZnCoFe and Cd outperforms all other coatings

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Coating Properties

Hardness

• Cd	~50 HV
• Zn	80 – 150 HV
• ZnCoFe	100 – 200 HV
• ZnNi (acid)	300 – 400 HV

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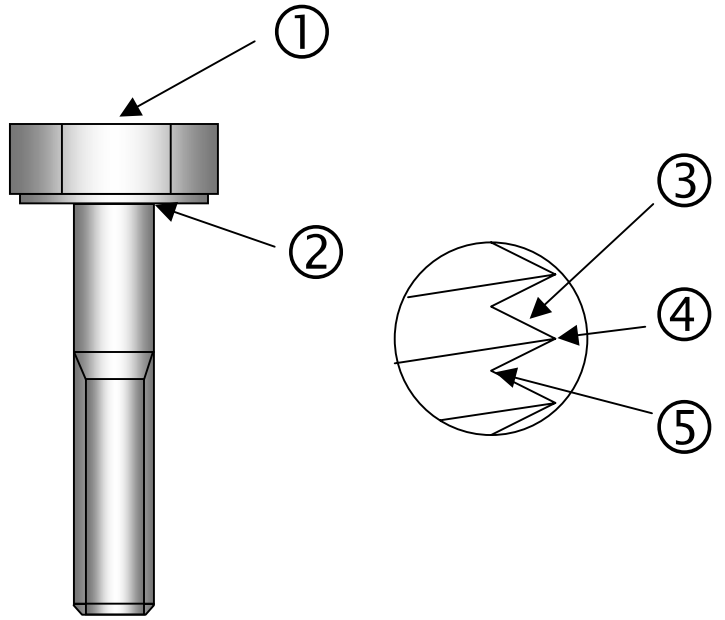
Throwing Power

Location	Coating ZnCoFe	Cd
1	8	8
2	6-8	5-8
3	3-5	4-5
4	4-5	3-5
5	4-5	3-5



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Effect on Fatigue Performance

Test:

- Constant amplitude fatigue tests were used
- Notched specimens were employed with stress concentration factors of 1.4, 2.5 and 4
- 1” diameter bars of AISI 4030 at HT200 were used. Strength level was 1400 MPa (~200 ksi).

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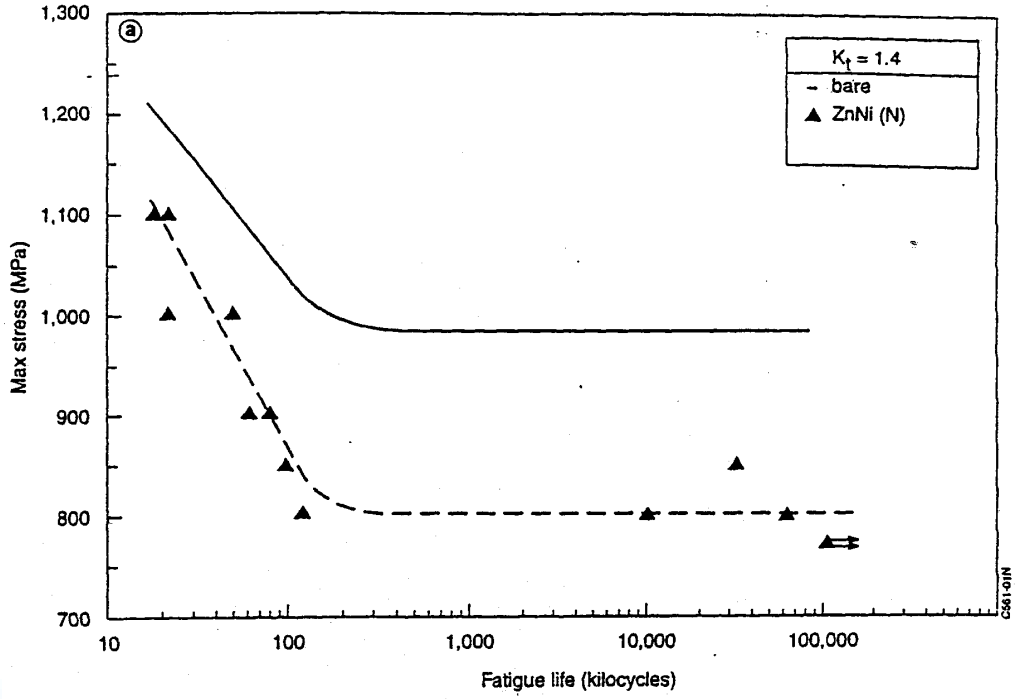
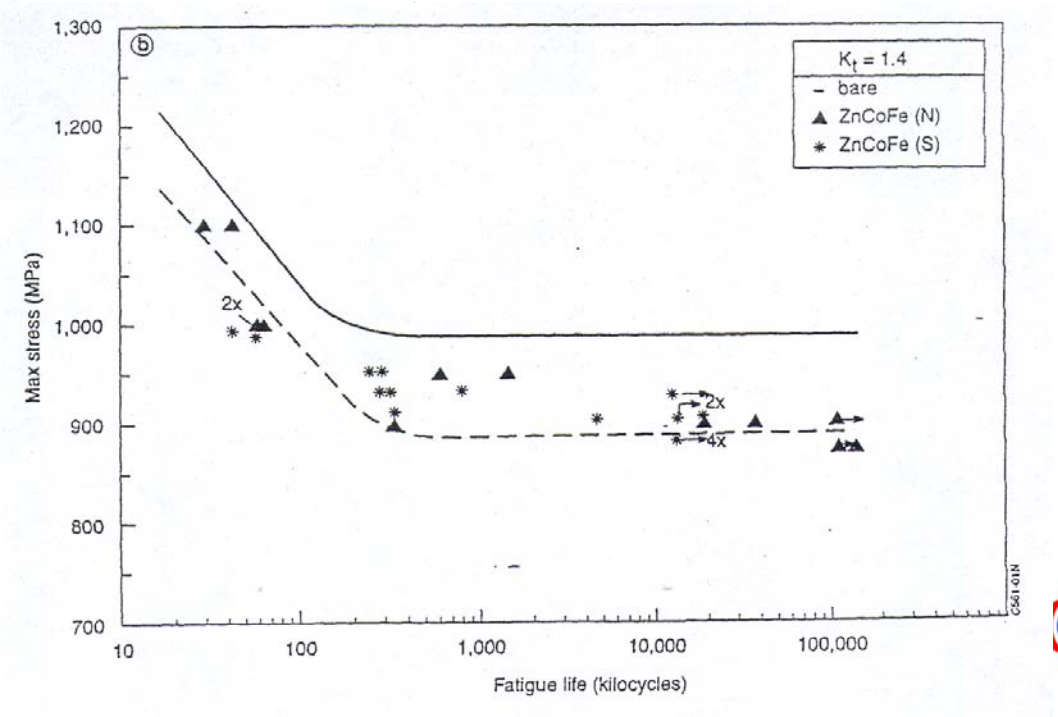

a
K_t = 1.4
bare
ZnNi (N)
Max stress (MPa)
1,300
1,200
1,100
1,000
900
800
700
10
100
1,000
10,000
100,000
Fatigue life (kilocycles)
C561-01N


b
K_t = 1.4
bare
ZnCoFe (N)
ZnCoFe (S)
Max stress (MPa)
1,300
1,200
1,100
1,000
900
800
700
2x
2x
4x
10
100
1,000
10,000
100,000
Fatigue life (kilocycles)
C561-01N

Effect on Fatigue Performance

Results:

- Zn-Ni ~20% reduction
- ZnCoFe, Cd ~10% reduction
- ED-Al, SermeTel, Delta-tone, Al-Mg ~5% reduction

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Stress Corrosion Cracking

Test:

- AISI 4340 notched steel substrates at 1800 MPa (260 ksi) were coated
- SCC tested by alternate immersion in 3.5% NaCl solution
- ZnCoFe coated samples failed
- Al based coatings passed

⇨ ZnCoFe coating only to be used to protect steel with UTS ≤ 1250 MPa (180 ksi)

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Hydrogen Embrittlement

Test:

- AISI 4340 notched steel substrates at 1800 MPa (260 ksi) were coated
- Samples tested at 75% of notch strength for 200 h
- Bright Cd fails
- ZnCoFe passed

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Tribological Properties

Tension torque tested

Comments:

- Same preloading required for ZnCoFe and Cd

Comments on producibility

ZnNi – no experience at Saab - 2nd hand information from Garteur partner (Shorts Brothers, Belfast, UK)

- Experiencing reproducibility difficulties – maintaining alloy composition
- ZnNi is hard – creates abrasive media in threads

Reduced fatigue strength

Comments on producibility

ZnCoFe

- Advantages
  - No corrosion issues over 10 years experience
  - Drop in for Cd
  - Conventional wastewater treatment
  - Less expensive than Cd
- Limitations
  - Not to be used on steel UTS ≥ 1250 MPa (180 ksi)
  - Not to be used on parts for electrical connections

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Usage Today

Parts manufactured at Saab to be used on JAS 39 Gripen multipurpose jet fighter on:

	Cd	ZnCoFe
• Fasteners	214	284
• Bushings	111	628
• Other	197	405
• **Sum**	**522**	**1317**
	28 %	**72 %**

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Usage Today

Parts manufactured at Saab to be used on JAS 39 Gripen multipurpose jet fighter on:

	Matte Cd	Bright Cd	Bright Cd El. Appl.	ZnCoFe
• Low alloy steel				
– <1100 MPa (160 ksi)			55	1003
– 1100 – 1250 MPa		2	9	28
– >1250 MPa (180 ksi)	406	17		
• Stainless steel		2	19	91
• Cu base alloys		10	2	191

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Present Process

ZnCoFe today

- Zincrolyte NCZ 191
- Simple to use
- Control:
  - [Zn], [OH], [Co], [Fe], [CO_3]
  - Hull Cell
- Zn anodes

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Concluding remark

- Saab is probably the only aerospace industry using ZnCoFe.
- BAE is evaluating the process.
- Process is used in automotive mainly as ZnFe or ZnCo.