



## Surface appearance of copper-based materials at unsheltered marine conditions



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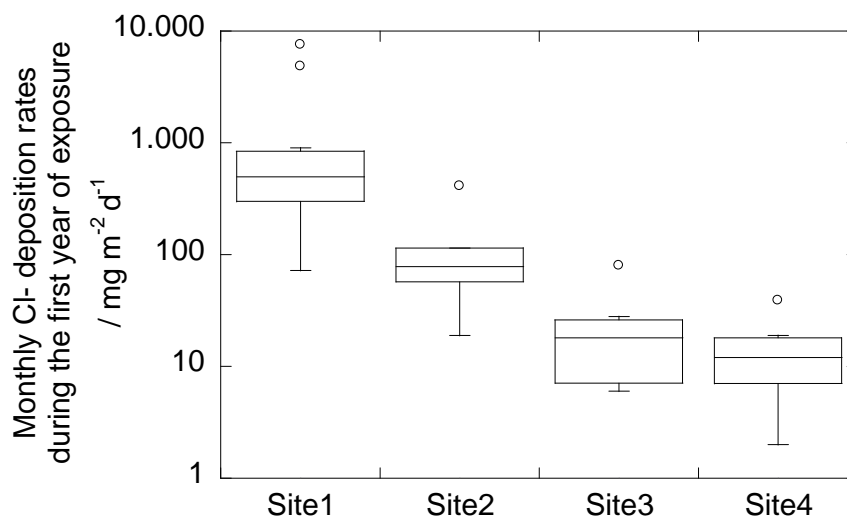
Prof. Inger Odnevall Wallinder, PhD ([ingero@kth.se](mailto:ingero@kth.se))



# Exposure sites in Brest, France

Exposure site	Distance from sea shore	Corrosivity category	Measured first year corrosion rate (g/m <sup>2</sup> /y)
1 Base Navale	<5 m	C <sub>5</sub> (very high)	24
2 St Anne	25 m	C <sub>4</sub> (high)	16
3 St Pierre	1.5 km	C <sub>3</sub> (moderate)	12
4 Langonnet	40 km	C <sub>3</sub> (moderate)	9

Corrosivity categories according to the ISO 9223 and ISO 9225 standards on Corrosion of metals and alloys





# Cu sheet (45° South)

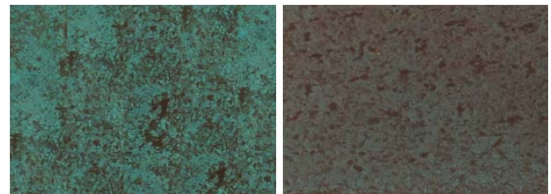
unexposed



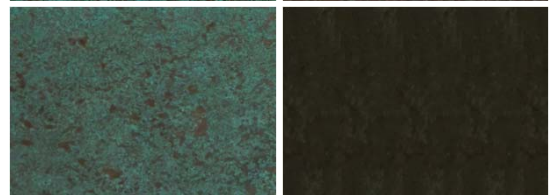
6 months

Site 1

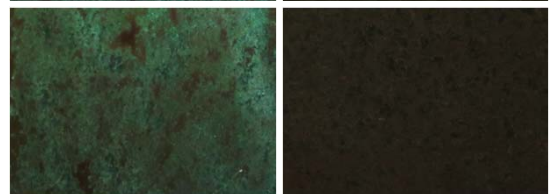
Site 2



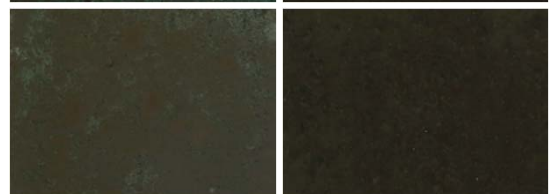
1 year



3 years



4 years



5 years



Site 1

Site 2

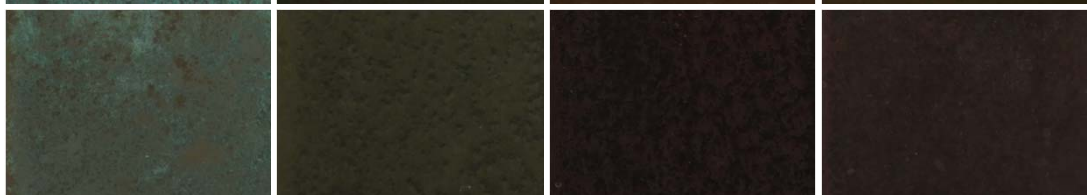
Site 3

Site 4

Year 1



Year 5





# Cu sheet (45° South)

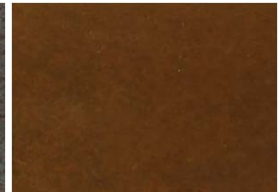
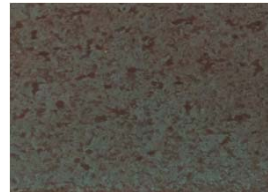
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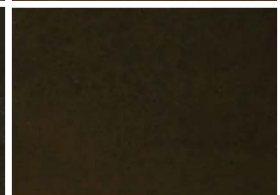
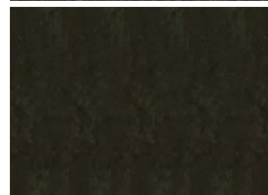
6 months

Site 2

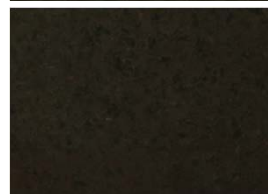
Site 4



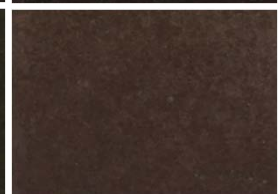
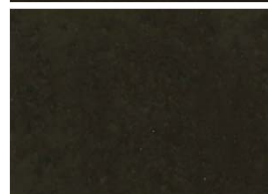
1 year



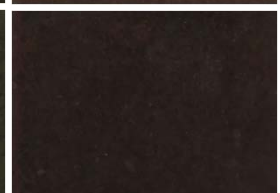
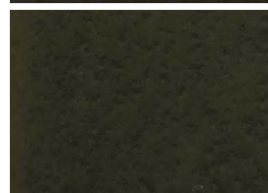
3 years



4 years



5 years



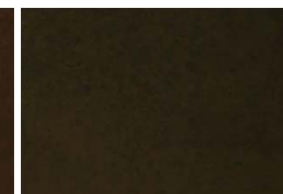
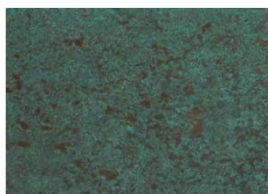
Site 1

Site 2

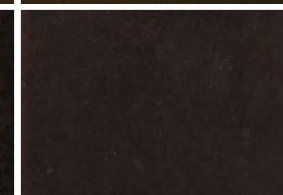
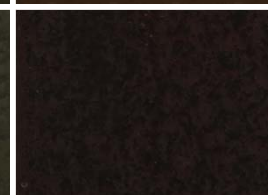
Site 3

Site 4

Year 1



Year 5





# Cu sheet (45° South)

unexposed



	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				



# Cu sheet (90° South)

unexposed



6 months

1 year

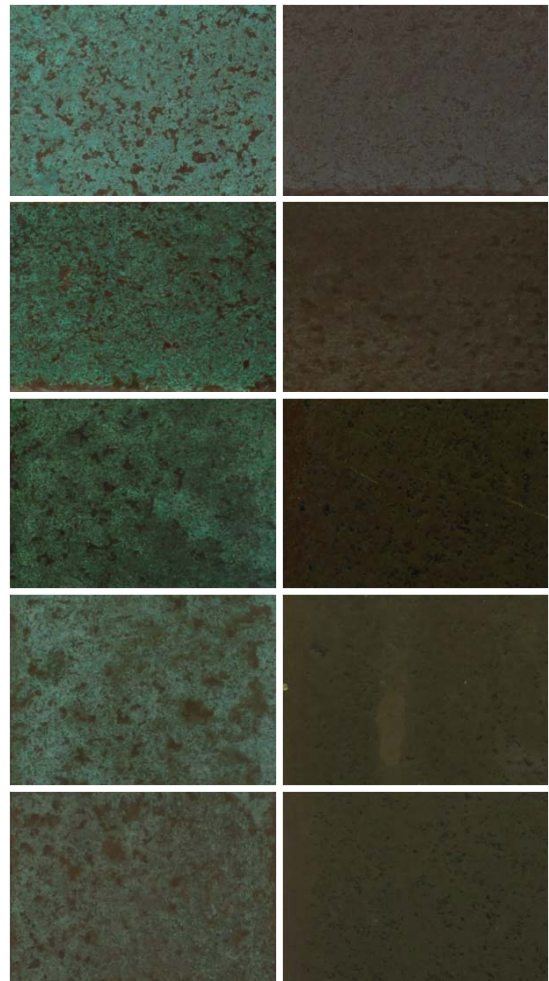
3 years

4 years

5 years

Site 1

Site 2



Site 1

Site 2

Site 3

Site 4

Year 1

Year 5





# Cu sheet (90° South)

unexposed



6 months

1 year

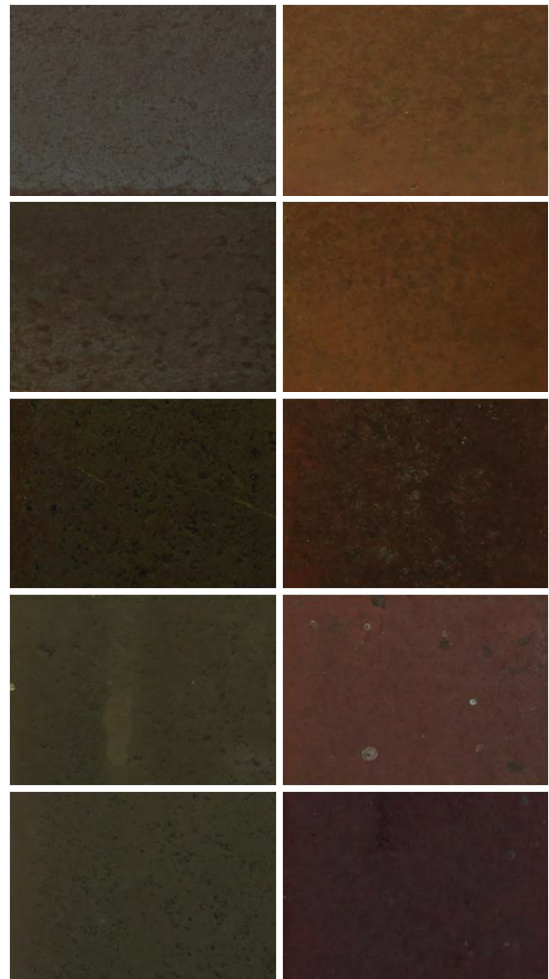
3 years

4 years

5 years

Site 2

Site 4



Site 1

Site 2

Site 3

Site 4

Year 1

Year 5





# Cu sheet (90° South)

unexposed



	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				





# BRASS – CuZn15 (45° South)

unexposed



6 months

Site 1

Site 2



1 year



3 years



4 years



5 years



Site 1

Site 2

Site 3

Site 4

Year 1



Year 5





# BRASS – CuZn15 (45° South)

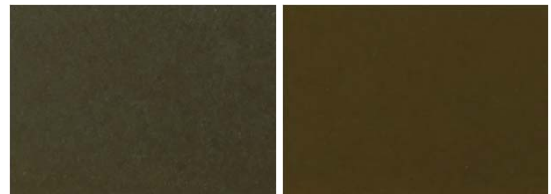
unexposed



6 months

Site 2

Site 4



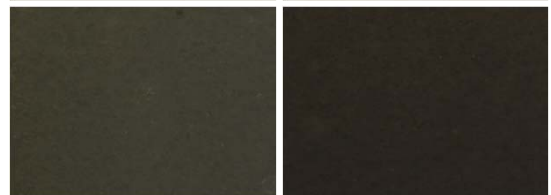
1 year



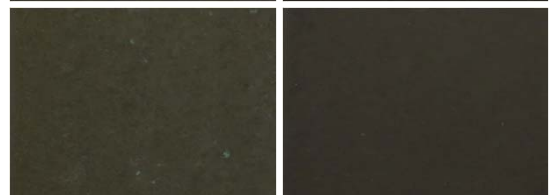
3 years



4 years



5 years



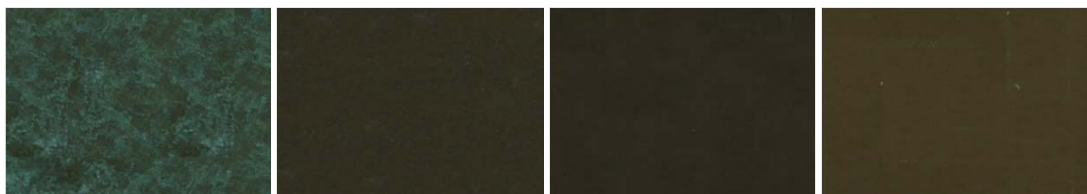
Site 1

Site 2

Site 3

Site 4

Year 1



Year 5





# BRASS – CuZn15 (45° South)

unexposed



	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				



# BRASS – CuZn15 (90° South)

unexposed



6 months

Site 1

Site 2



1 year



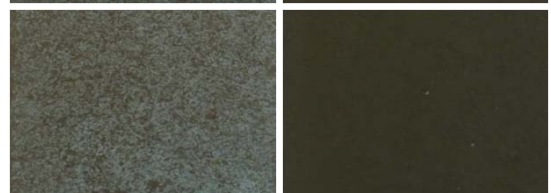
3 years



4 years



5 years



Site 1

Site 2

Site 3

Site 4

Year 1



Year 5





# BRASS – CuZn15 (90° south)

unexposed



6 months

Site 2

Site 4



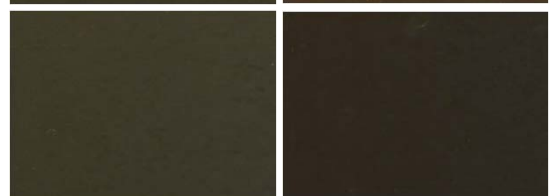
1 year



3 years



4 years



5 years



Site 1

Site 2

Site 3

Site 4

Year 1



Year 5





# BRASS – CuZn15 (90° South)

unexposed



	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				



# BRONZE, CuSn4 (45° South)

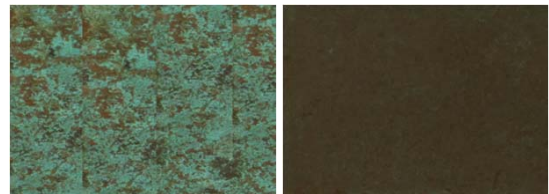
unexposed



6 months

Site 1

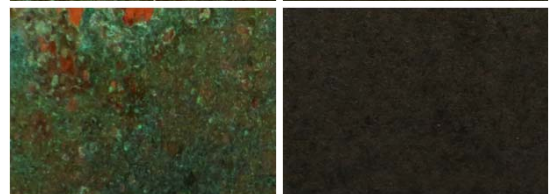
Site 2



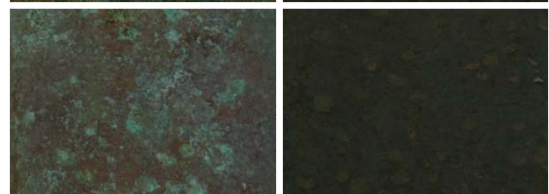
1 year



3 years



4 years



5 years



Site 1

Site 2

Site 3

Site 4

Year 1



Year 5





# BRONZE, CuSn4 (45° South)

unexposed



6 months

Site 2

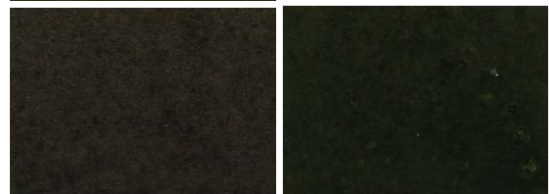
Site 4



1 year



3 years



4 years



5 years



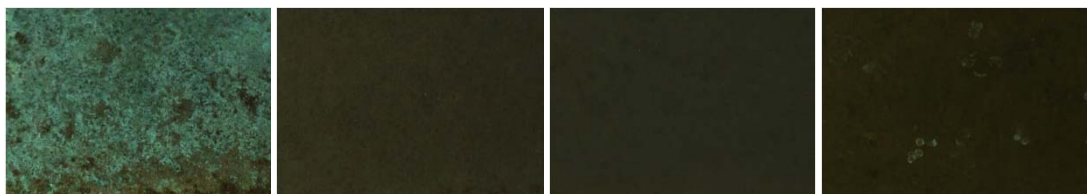
Site 1

Site 2

Site 3

Site 4

Year 1



Year 5







# BRONZE, CuSn4 (45° South)

unexposed



	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				



# BRONZE, CuSn4 (90° South)

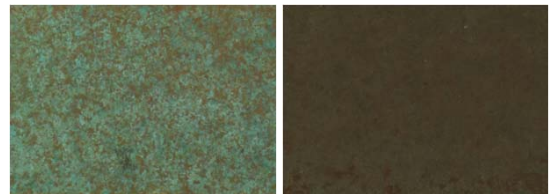
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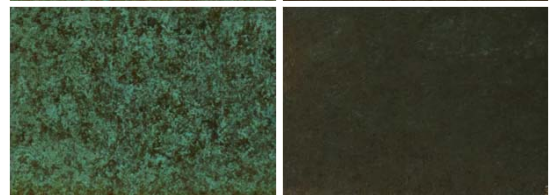
6 months

Site 1

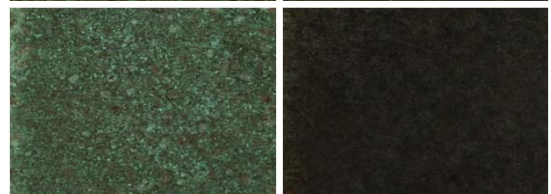
Site 2



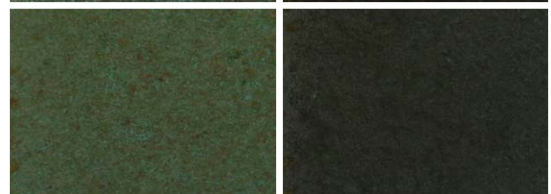
1 year



3 years



4 years



5 years



Site 1

Site 2

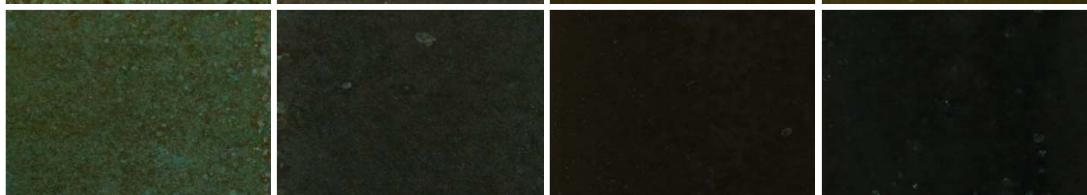
Site 3

Site 4

Year 1



Year 5





# BRONZE, CuSn4 (90° South)

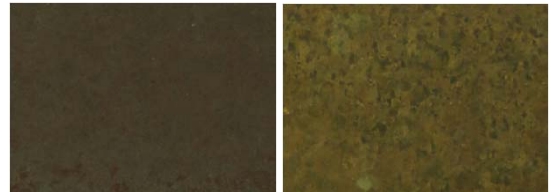
unexposed



6 months

Site 2

Site 4



1 year



3 years



4 years



5 years



Site 1

Site 2

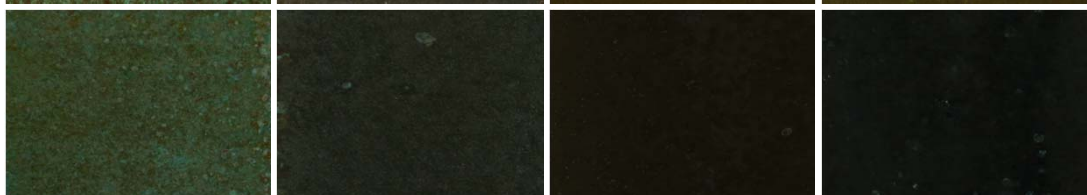
Site 3

Site 4

Year 1



Year 5





# BRONZE, CuSn4 (90° South)

unexposed



	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				



# GOLD COLOURED ALLOY (45° South)

unexposed



6 months

1 year

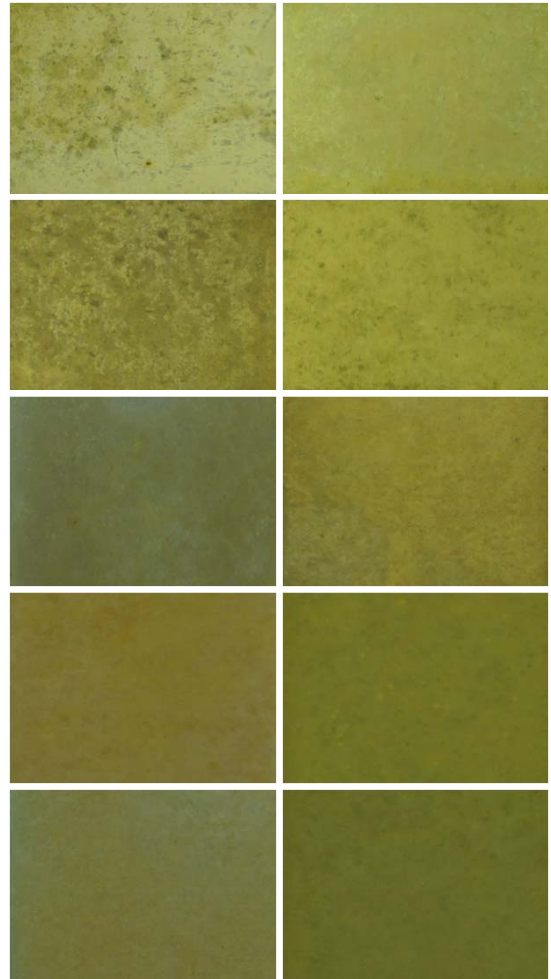
3 years

4 years

5 years

Site 1

Site 2



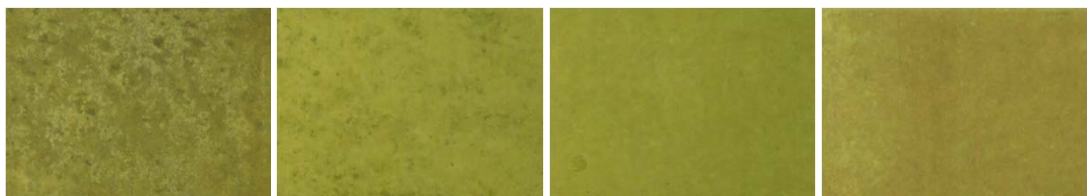
Site 1

Site 2

Site 3

Site 4

Year 1



Year 5





# GOLD COLOURED ALLOY (45° South)

unexposed



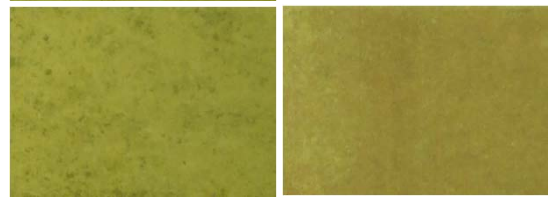
6 months

Site 2

Site 4



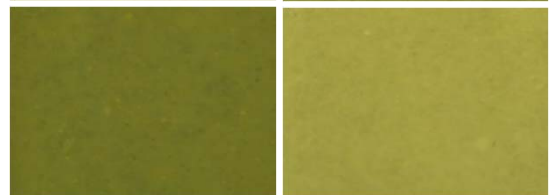
1 year



3 years



4 years



5 years



Site 1

Site 2

Site 3

Site 4

Year 1



Year 5





# GOLD COLOURED ALLOY (45° South)

unexposed



	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				



# GOLD COLOURED ALLOY (90° South)

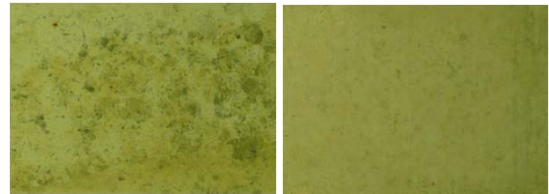
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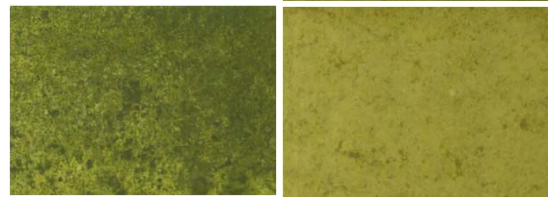
6 months

Site 1

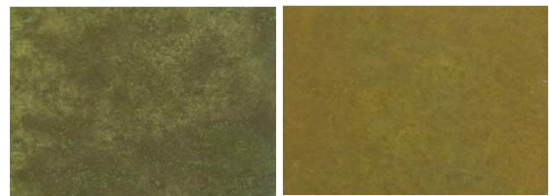
Site 2



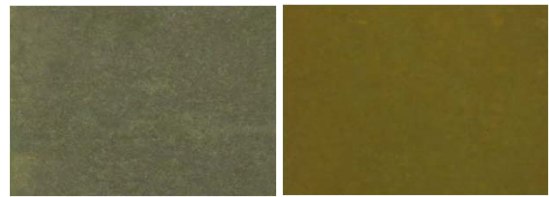
1 year



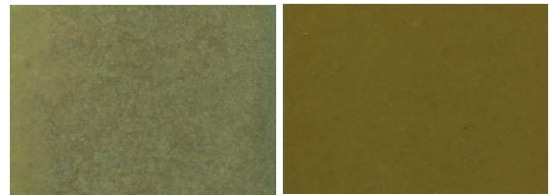
3 years



4 years



5 years



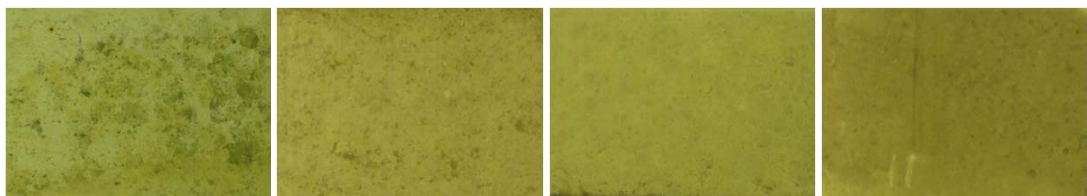
Site 1

Site 2

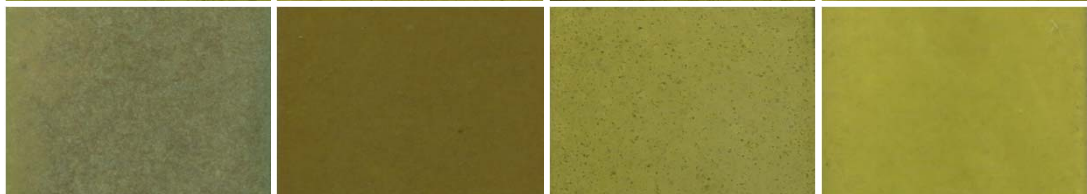
Site 3

Site 4

Year 1



Year 5







# GOLD COLOURED ALLOY (90° South)

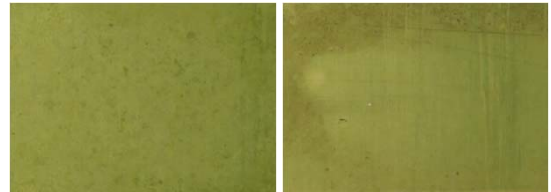
unexposed



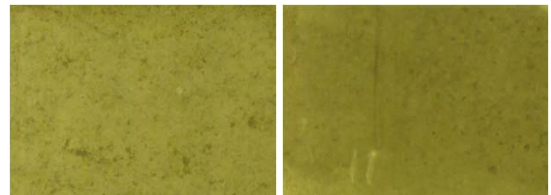
6 months

Site 2

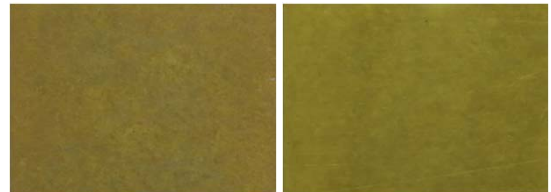
Site 4



1 year



3 years



4 years



5 years



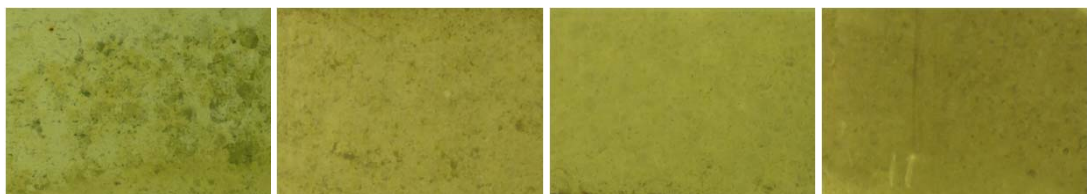
Site 1

Site 2

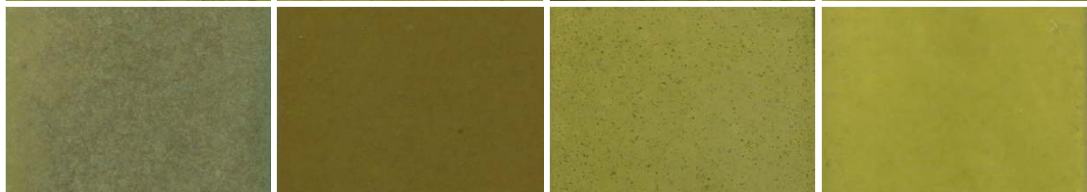
Site 3

Site 4

Year 1



Year 5





# GOLD COLOURED ALLOY (90° South)

unexposed

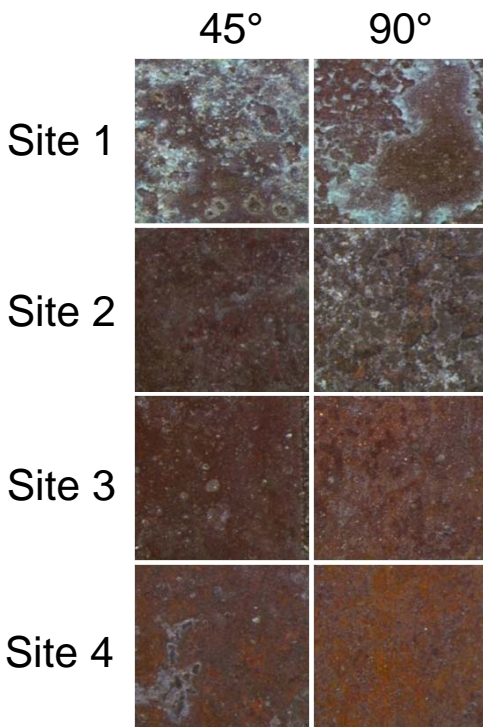


	Site 1	Site 2	Site 3	Site 4
6 months				
1 year				
3 years				
4 years				
5 years				



# Quantifying surface appearance

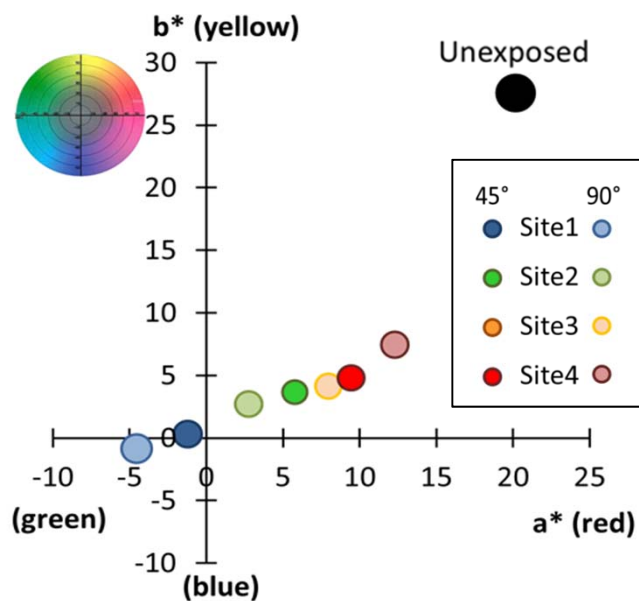
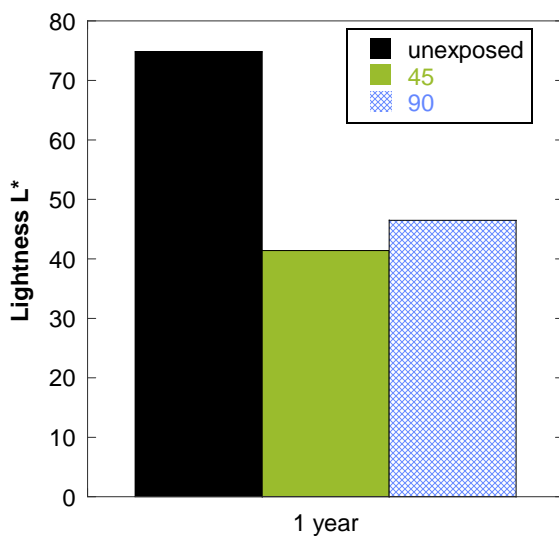
## Cu sheet – 1 year



## Spectrophotometry

The surface appearance can be quantified scientifically using for example spectrophotometry. This is a useful tool that enables comparison between different surfaces as the appearance is very different depending on e.g. light and weather conditions in addition to patina characteristics. Spectrophotometry measures the reflected and/or scattered light from a well-defined white light source illuminated on a surface at a given angle. Absorption of light gives a measure of the surface brightness.

[Atmospheric Corrosion, 2<sup>nd</sup> ed, C. Leygraf, I. Odnevall Wallinder, J. Tidblad, T.E. Graedel, John Wiley & Sons, New York, US (2016)]





## Key references

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2. *Mechanistic studies of corrosion product flaking on copper and copper-based alloys in marine environments*, X. Zhang, I. Odnevall Wallinder, C. Leygraf, *Corrosion Science*, 85, 15-25 (2014)
3. *The protective role of hydrozincite during initial corrosion of a Cu40Zn alloy in a chloride-containing laboratory atmosphere*, X. Zhang, X. Liu, I. Odnevall Wallinder, C. Leygraf, *Corrosion Science*, doi:10.1016/j.corsci.2015.10.027 (2015)
4. *Surface-rain interactions: Differences in copper runoff for copper sheet of different inclination, orientation, and atmospheric exposure conditions*, Y. S. Hedberg, S. Goidanich, G. Herting, I. Odnevall Wallinder, *Environmental Pollution*, 196, 363-370 (2015)
5. *Critical review: Copper runoff from outdoor copper surfaces at atmospheric conditions*, Y.S. Hedberg, J.F. Hedberg, G. Herting, S. Goidanich, I. Odnevall Wallinder, *Environmental Science and Technology*, 48, 1372-1381 (2014)
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7. *The evolution of outdoor copper patina*, A. Krätschmer, I. Odnevall Wallinder, C. Leygraf, *Corrosion Science*, 44(3), 425-450 (2002)
8. *Atmospheric Corrosion*, 2<sup>nd</sup> ed, C. Leygraf, I. Odnevall Wallinder, J. Tidblad, T.E. Graedel, John Wiley & Sons, New York, US (2016)

Additional publications and reports available via: <https://www.kth.se/profile/ingero/>

The results presented are a result of a long-term research collaboration on atmospheric corrosion of copper and copper based alloys between KTH Royal Institute of Technology and ECI/ICA.

Camera settings: Canon G16; ISO 400; f/2.8; 1/200; measured by Polaris flash meter.

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