HANDBOOK OF DAMAGES FOR REFERENCE IN ART CONSERVATION

METALS

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SUPPORTED UNDER THE TATA TRUSTS ART CONSERVATION INITIATIVE

TATA TRUSTS

Introduction

Since 2019, the Tata Trusts Art Conservation Initiative has been actively engaged in establishing, developing and strengthening art conservation centres in five zonal locations across India, and creating a cohort of trained art conservators. One of the key objectives of the initiative was to design and implement 3-month-long, practicals-intensive training courses in conservation of ten specific materials: stone, wood, oil paintings, metals, natural history specimens, paper (prints, drawings and maps), paper (manuscripts and miniature paintings), photographs, textiles and wall paintings. Through 2021 to 2023, nine such courses have been conducted in collaboration with the five zonal partner institutes across five geographical regions of India. Through the courses, data has been collected pertaining to damages and deterioration commonly seen in art objects of varied materials that has aided conservators in charting appropriate treatment plans for their objects. Data was also sourced from a previous Tata Trusts supported project – the Art Conservation Resurgence Project (ACRP), with Chhatrapati Shivaji Maharaj Vastu Sangrahalaya (CSMVS), Mumbai.

This Handbook of Damages for reference in Art Conservation is a digital visual guide developed to aid and assist art conservators as well as custodians of art collections, to correctly identify damages, their causes and effects, in order to plan for their conservation treatment. It also informs the custodians of how the deterioration will progress if not arrested in time. It is intended to be a glossary for practical use, categorized material-wise, and is a work in progress as listing possible damages and deterioration is not an exhaustive exercise. As more examples of deterioration are sourced from various contributors, they will be added to the handbook. The reader is encouraged to observe the damage on the actual object, broadly categorise it, and match the visual in the book. Following this identification, the handbook can guide in understanding the probable reason and basic mechanism of how the deterioration proceeds, and what it could lead to. As the glossary is updated over time, literature references and reading lists will also be added. While the handbook hopes to be a source of practical information, the reader is advised to consult an art conservator or material expert before proceeding with conservation or restoration treatment.

This chapter of the Handbook focuses on metals, covering common and unusual damages seen in a variety of metals and alloys of iron, tin, lead, copper, zinc, and others. The damages are categorised as surface deposits, mechanical damage, chemical damage, or biological growth.

Acknowledgements

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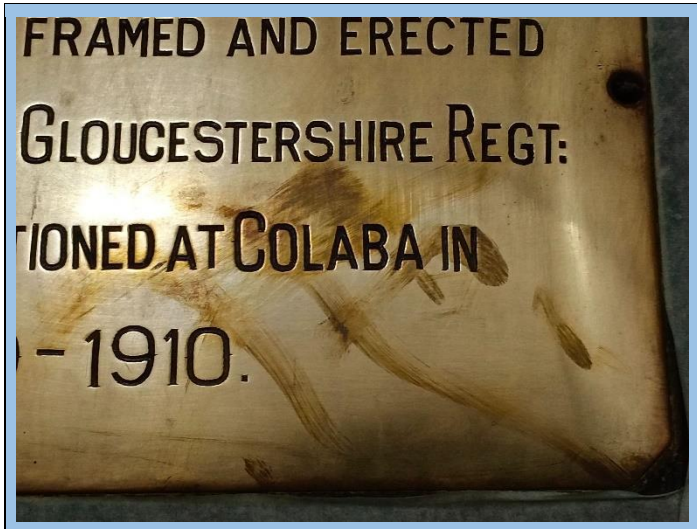
Types of damages

Surface deposits	Defined as accumulation of foreign material of variable thickness on the surface of any material. Some examples of deposits include paint or mortar, sea salt, aerosol particles such as soot or dust, biogenic deposits etc.
Mechanical Damage	Defined as a loss of material due to mechanical action. Some examples of mechanical damage include overlaid physical stress - intentional or accidental, and abrasion.
Chemical Damage	Defined as the deterioration of material due to a chemical reaction. Some examples of chemical damage include the different types of corrosion, including those caused due to interaction with atmospheric elements.
Biological growth	Defined as the steady build up of biological and microbiological formations and organisms on the surface of any material. Some examples include moss, lichen, plant and root growth, insect colonisation etc.

SURFACE DEPOSITS			
Image	**Term and Description**	**Probable Cause & Mechanism of Damage**	**Effect**
	**Rust stains/Encrustations** Residue of the corrosion left behind on the surface of the metal or adjoining/adjacent surfaces. Encrustation- When the iron object severely corrodes there can be transfer of rust particles - deposition to the adjacent surfaces.	In the presence of moisture the iron corrosion products get deposited on the top layer of the adjacent surface. In this case the rust particles have broken through the overlying shiny plated surface and deposited over it.	Stains and encrustations affect the visual appearance of the object. Stains transferred to other adjacent surfaces may affect the materiality of those surfaces, for example stains on paper, wood, or textile.
	**Inclusion** These are not really deposits bit more like protuberances that can be observed on metal surfaces as if some material is embedded under the surface of the metal.	During casting of metals foreign materials sometimes get trapped inside the metal.	This leads to an inherent loss of strength. Depending on the nature of the inclusion it can affect the properties of the base metal. This in turn can weaken the strength of the metal

	**Accretion** Often we find deposits of earth, cementitious layers, and other foreign materials on the surface of metal objects. Some of these are hard, while some come off easily. These are referred to as accretions. Accretions are usually of a substantial thickness.	Some of these are formed as deposits or layers on the object, while they can also be accumulation of matter due to corrosion or interaction of the metal object with the environment.	It alters the visual appearance of the object, and hides the designs, inscriptions or other decorative details. If left untreated over a long period of time accretions may harden and become very difficult to remove later on.
		Accretions can also be deposited when cleaning abrasives like brasso or silvo are used on objects. After some time the residues get deposited in the areas from where they cannot be removed easily. When the cleaning agent dries up, they become starkly visible as whitish-greyish deposits	
	Dark coloured fine deposits over copper alloy objects.	Soot and grime deposit on the metal objects either from polluted environments or due to the oil lamps and fires used during rituals.	The dark deposits visually alter the appreciation of the object. If soot deposits remain over time, they may act as acid compress in polluted environment.

	**Stains** Dark marks on copper alloy objects with visible fingerprints.	This is typically indicative of touching the silver or copper alloy objects with bare hands. Moisture, salts in our sweat react with the copper alloy causing oxidation, and leading to the dark stains.	Hinders the visual appearance of the object. If left unchecked, it can expose the base metals to moisture and other elements leading to further chemical damage and in time induce corrosion.
	Sometimes light bluish marks can be seen on sculptures kept in the open air, under trees and other vegetation.	Bird droppings as well as exudations from trees cause these stains to form on the surface of the objects. Mild acids in the plants cause reaction with the copper rich surface. The bird droppings are acidic in nature (uric acid) and cause oxidation of the base layer of the metal, or removes the fine layers of any surface coats that may have been applied.	

MECHANICAL DAMAGE			
Image	**Term and Description**	**Probable Cause & Mechanism of Damage**	**Effect**
	**Abrasion** Fine scratches can be seen on the surface	Abrasions form when a hard material scratches the surface of the metal. Sometimes while cleaning it with a hard and rough mechanical action the surface may get abraded. That is why cleaning materials like scotch brite or metal scrubs are avoided. Often when objects are stored with other objects, relative movement between them also cause this physical damage.	It disturbs the visual appearance of the object. Scratches are irreversible as they imply loss of material from the surface. In some cases the functionality of the object may also be lost. The surface of objects often develop a protective coating, such as oxide layers on copper objects, and abrasions indicate that at those points, this coating may have been scratched away and may expose the metal to corrosive effects of a polluted environment.

	**Dent**s On the surface of metals there can be observed depressed areas that may also be accompanied by cracks around the area or in the centre of the crater.	These may be caused due to sharp blows on the object or due to a weight on the object over time that causes the softer metal to deform.	Other than affecting the visual aspect of the object, a dented object could get physically damaged further at the weak points, and corrosion may also set in at the cracks as those areas will be vulnerable to action of salts in the environment.
	**Cracks and metal fatigue** Fine or wide cracks visible on the surface may run along the object leading to separation that may be very fine or wide enough to be noticed from a distance. Near some cracks, fine striations can be seen and these are indicative of metal fatigue.	Cracks may form due to weakening of the metal. They could form if the objects are subject to physical stress. They can also be caused due to expansion of the metal or thinning of the metal due to corrosion. When the stresses are cyclic or repetitive, then metal fatigue sets in and fractures develop.	Other than affecting the visual aspect of the object, a cracked object could get physically damaged further at the weak points and break apart. Corrosion may also set in at the cracks as those areas will be vulnerable to action of salts in the environment.

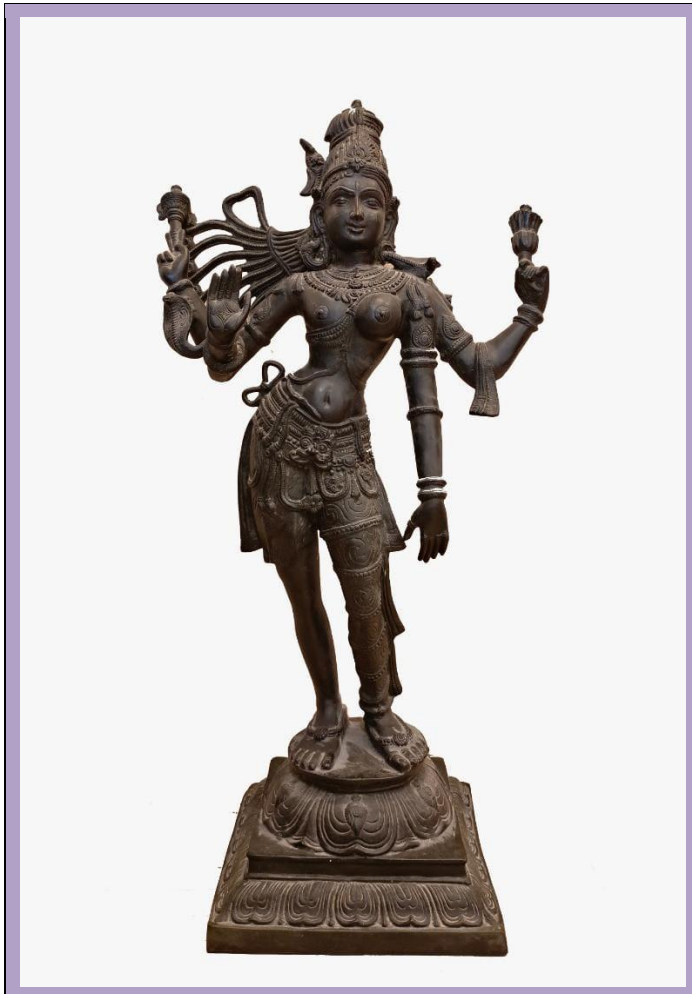
	**Deformation** The shape of the object is visibly and physically changed.	Metal objects may deform due to overlaid stress on them.	If the deformation is accentuated or if the stress continues to act on the metal, then they may even fold over and develop cracks at the line of the folds or deformity.
	**Folds** Sometimes deformed metal objects may bend so much that they almost fold over. This is evident on the thinner sheets of metal objects, often at the edges or corners which are more prone to folding.	Metals deform to the point of folding if stresses on them are large and if pressure on the weak sheet is sustained over time.	If left untreated can lead to crevice corrosion due to the accumulation of moisture/water in the folded area. Cracks may also develop along the line of the fold.

	**Holes** Small punctures or large openings may run right through the thickness of metals.	Holes may form due to physical stress at particular points or in areas where other elements are fitted into the object. At these points corrosion may set in. When pitting corrosion sets in, and continues unchecked, it may lead to punctures in the metal.	Holes would alter the visual aspect of the object, and if unchecked may enlarge over time due to further mechanical damage or due to corrosion setting in along its edges. Holes may weaken the object as the strength of the metal is reduced. As stresses are magnified at such locations, the object may also give way due to its own weight.
	**Delamination** Layers of metal come off the surface of the base metal on which they were adhered or inlaid. The base metal is exposed.	This is caused due to a reduction in coating adhesion between metal layers. The coating adhesion is reduced due to corrosive action and/or due to mechanical stress.	It affects the visual appearance of the metal object as well as exposes the base metal to further corrosive action affecting the stability and strength of the object.

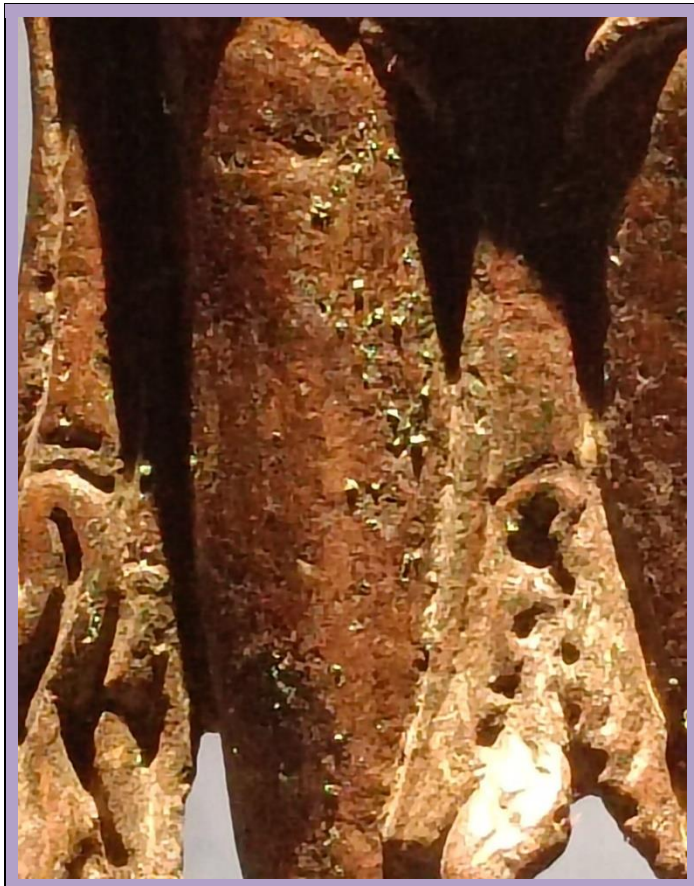
	**Gash** A deep cut in the metal sheet or substrate of a metal object.	Caused due to a hard blow by a sharp object.	Affects the visual appearance of the object and also exposes the metal substrate to further chemical or mechanical damage.
	**Loss of gemstones** Absence of gemstones inlaid in the grooves of the metal objects.	Weakening of the adhesive between the gemstone and metal groove; or due to mechanical pressure or breakage.	Affects the visual appearance of the metal object as well as its monetary value.

	**Loss of gilding** Loss of gilding from the surface of the metal.	Caused due to mechanical abrasion or bimetallic corrosion (when two dissimilar metals corrode disproportionately when exposed to electrochemical processes, caused naturally or mechanically).	Affects the visual appearance of the metal object and can affect its monetary value as well as gilding is often done using gold. Further corrosive action is also a possible effect.
	**Loss of painted, inlaid lettering** Chipping of the letters can be observed especially under raking light.	Caused due to mechanical stress, or radical change in temperature that causes the paint to embrittle and break. It may also happen due to the ageing of the filler.	Affects the legibility of the text. If not arrested, remaining letters too may be lost.

	**Previous repairs** These signs of repair include welding, brazing, soldering or mechanically joining broken or separated elements.	These are not damages as such, but if dissimilar metals are used, galvanic corrosion may happen.	Unfinished repairs may affect the visual appearance of the metal objects. If dissimilar metals are used in the joinery or repair process, then it may lead to further chemical damage.
CHEMICAL DAMAGE			
Image	**Term and Description**	**Probable Cause & Mechanism of Damage**	**Effect**
 	**Rust** A reddish brown or orange layer, rough to touch, can be seen and felt on objects made of iron. Rust is present as thin layers and may also be evident as thick corrosion, often accompanied with flaking and breaking up of the surface of the metal. Active rusting is often identified with its orange coloured hue.	Rust forms on ferrous objects and is caused by the action of moisture, oxygen, sodium chloride, etc. present in the atmosphere. The water and oxygen molecules react with iron to form isomers of ferrous oxide and ferrous oxyhydroxide (FeOOH).	If left untreated, rust develops from a fine layer on top of the ferrous metal to thick layers that may flake off and lead to thinning of the metal. If unchecked, the entire iron object may get corroded till the core and when subject to any pressure or stress, the object may fragment and crumble to powder. When iron dowels or nails rust, they expand and pry apart and break the material that they were supposed to hold together. Rust will also stain the surrounding material.

	**Patina** On a metal object, the surface of the object often carries a coating or a fine latter or a tone that is different than the original colour of the surface. This colour could be be of various hues of green, blue, red, browns, whites, greys etc. It may appear as uniform surface or as as crust. One must differentiate patina from surface deposits of foreign material on the surface of the object. After a prolonged period of time, metals develop a layer on the surface. This layer could be protective or it could be due to corroded compounds known as patina. Common colours of the compounds causing patina are dark brown, reddish brown, green, blue, bluish green (for copper alloys) Red, orange, brown (for ferrous alloys) Whitish and greyish (for tin, aluminium, lead)	Patina is generally caused due to the reaction of the object with the environment over a period of time, and is also associated with the ageing of the object. moisture and salts (formed from pollutant gasses like hydrogen sulphide, sulphur dioxide, carbon dioxide, etc.) with the metal surface. **Noble Patina/Natural Patina** - Forms naturally due to chemical reaction of the metal with moisture and pollutants. Stable in nature and it enhances the surface appearance of the object. Patina is formed by various metal compounds like oxides, carbonates, sulphates etc. **Artificial patina:** Created artificially with the help of various chemical formulations. **Cosmetic Patina:** Created artificially to enhance the aesthetic appeal of the object by imparting unnatural colors on the metal surface.	Patina is generally considered to enhance the aesthetic appeal of the metal object. It also protects the metal object from further corrosion by forming a protective layer. In some cases if a corrosion layer is harmful to the object, such as due to copper disease, then this layer is removed as it is endangering the life of the object.

  *From top: Photo by CEphoto, Uwe Aranas; image sourced from Maverick Inspection website*	**Hydrogen embrittlement/cracking** Hydrogen cracking appears as long cracks along the surface of the metal object, can be seen near welded joints as well. **Hydrogen blistering** Hydrogen blistering appears as sacs or bubble-like appearance on the surface of the metal.	During casting and melting, sometimes, metals like steel and titanium pick up hydrogen from atmosphere. This leads to formation of metal hydrides which are brittle in nature If the rust or iron oxides are not removed before painting a metal surface, then, the metal beneath the paint continues to oxidise resulting in formation of blisters.	This reduces the mechanical strength of these metals making it vulnerable to further corrosion. This is one of the main reasons why paints fail on metals.

	**Copper disease, also sometimes called copper cancer or bronze disease** Pin-head sized, light green, powdery fluffy dots seem to come out of the surface of the copper alloy object. They can be brushed away easily, and they reappear after another day passes.	This corrosion is caused as a result of a complex chemical reaction between water/moisture, chlorides and copper alloys. Hydrochloric acid is formed as a result of this reaction, which eats away at the metal. It is an irreversible corrosive reaction and is extremely harmful to the metal object.	This is an active corrosion and if not treated, then it continues to weaken the copper alloy object leading to its disintegration. It affects the visual appearance of the metal object, but more importantly it corrodes the metal irreversibly.

 	**Pitting corrosion** Small pits, usually dark in colour can be seen on the metals such as ferrous and copper alloys. In the case of copper or copper alloys, pitting corrosion appears as small bright green, powdery pustules.	It is a localized galvanic corrosion and localised deposition of corrosive materials like dust, chloride containing chemicals. When two or more dissimilar metals are in contact with each other, then a voltage (potential difference) is generated which leads of corrosion of the metal that is lower in the emf series. For example on a steel sword, pitting corrosion will occur if it is in contact with copper. In case of lead coins in aluminum box, the lead will corrode.	It leads to loss of strength of the object. If not treated, corrosion continues into the depth of the metal and may even form holes.

Corrosion

The surface of a metal object is covered with crusty deposits of varying colours.

For example:

Lead – the corrosion in lead appears whitish-gray. It is powdery and can be easily brushed away.

Tin – the corrosion of tin appears gray in colour.

Copper – the corrosion in copper appears in the following colours: reddish brown, blue, dark green, bluish green and the whitish green corrosion described earlier.

Corrosion in metals can manifest in several ways including the following: uniform corrosion, galvanic corrosion, crevice corrosion, inter-granular corrosion, stress corrosion, microbial corrosion, cavitation corrosion.

In the case of lead, the moisture reacts with the lead in the presence of chlorides and forms lead hydroxide.

In the case of tin, the metal reacts with oxygen and moisture to form tin oxide which is grayish in colour.

In the case of copper, the moisture in the air reacts to form copper oxide. Over a period of time, as the corrosion continues, the colour of the corrosion changes from red to black to green to blue.

The thickness of the lead coins and objects decreases leading to weakening and the objects may break in due course.

This is also a surface phenomenon, and does not harm the inner surface.

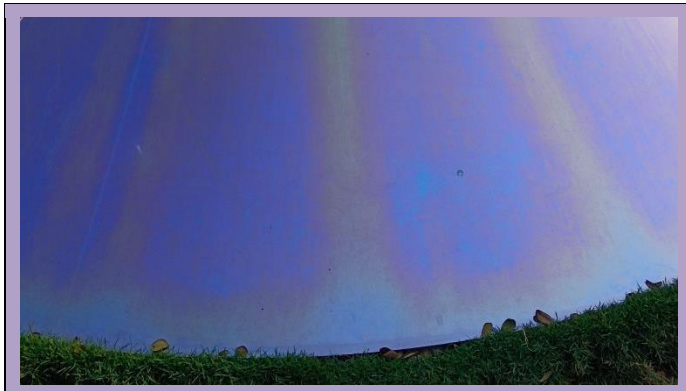
It affects the visual appearance of the metal object and depending on the level of corrosion it can weaken the strength of the metal and its ability to withstand pressure; in severe cases unexpected breakage of the object may occur.

	**Dezincification** If there is a brass object, there appear on it coppery or pinkish-reddish areas. Refers specifically to the leaching of zinc from brass, however the process is also known as ‘dealloying’, ‘selective corrosion’ or ‘selective leaching’.	In presence of acidic or alkaline environments, zinc is selectively leached out to the surface of a brass object (brass is an alloy of copper and zinc). This zinc is removed from the surface due to contact with water, and eventually makes the area rich in copper, and hence the pinkish colour. The pink colour of a leached brass surface may also turn reddish brown if the copper surface further corrodes. Sometimes commercial metal polishes or cleaning agents contain acids that can cause the dezincification.	Affects the visual appearance of the object and affects its material composition as zinc is leached away. In severe cases brass objects will become weak because copper is weaker than brass.
	**Weeping/Sweating Effect** The surface of the iron object has a number of globules or blister-like formation which is dark brown on orangish in colour. It breaks off easily and where the bubble or blister was, there appears an orangish round mark on the rusted metal.	Caused due to presence of chloride ions on iron surfaces. This results in formation of ferric chloride which is acidic in nature. Ferric chloride is hygroscopic and absorbs moisture to form the globules.	Affects the visual appearance of the iron objects and accelerates the corrosion process and rust formation.

	**Hard water stains** White stains and deposits on metal which has been in contact with water	The salts in the water get deposited on the metal surface once the water evaporates. Often these are calcium salts.	They disfigure the metal object and over time can be hard to clean off from the surface of the metal.
	**Tarnish** A grey or black layer is often seen on silver surfaces. The silver surface that is exposed to the atmosphere turns dark compared to those areas that have been sheltered. 	The silver reacts with moisture and sulphur containing gases (from vehicular pollution, or from sewage drains etc.). This sulphur reacts to form silver sulphide that is black in colour.	It leads to loss of the silvery shine of the object. It does not further damage the underlying silver surface.

	**White deposits on galvanised steel objects** The surface of a zinc coated steel object (galvanized steel) has a white chalky deposit or layer forming on it.	This forms on newly galvanised steel objects or on other zinc rich materials that have not had enough time to form stable oxides. White rust forms on these new objects due to formation of zinc hydroxide and zinc oxide due to contact with moisture and oxygen. As zinc is deprived of air a 'black rust' forms which then turns into a reddish-brown rust as the zinc is completely deprived of air.	Other than being visually disturbing, it is a continuous active corrosion and will decrease the thickness of the zinc coating.
	**Aluminum hydroxide deposits** The surface of the aluminum is covered with a white colour rough textured layer. It is often less than 1mm thick and can be scraped away to expose a dull surface of aluminum underneath.	In dry environment, an oxide layer forms on the aluminum and is protective. In the presence of moisture a whitish layer of aluminum hydroxide may also form on the object.	The shine of the aluminum disappears and the white layer forms on it. As the deposit is not compact or dense, it allows the corrosion to continue and thus increasing the thickness of the hydroxide layer.

	**Chloride corrosion** White corrosion spots on a smooth aluminum surface. They are hard and often create a pit, and can be removed by scraping. It does not brush off easily.	The chlorine present in high humidity atmospheres, like coastal areas, reacts with the aluminum surface and forms aluminum chloride.	If not treated, the pitting corrosion continues deeper into the aluminum surface.
	**Streaks** Lines on the surface of the metals such as on iron and steel objects that are kept out in the open. These lines can be vertical, though sometimes streaks also form in curves and at angles.	These lines are often related to rain water running down the surface of the metal sculptures/objects kept out in the open. When water runs down ferro alloy objects, they create reddish brown lines. In the picture, the white lines are due to rainwater trickling down the surface of a ferro alloy object that had been coated with a water repellant nano-coat, and it rained before the protective coat had cured properly.	The streaks could be considered as part of the natural interaction of the object with the environment. Alternatively, they may also be considered disfiguring. The white streaks due to the interaction of moisture with the uncured nano-coats are very difficult to remove.

	**Iridescence** A rainbow coloured tint on shiny stainless steel objects.	When stainless steel objects contain a bit of chromium, in the presence of air and heat, rainbow tints may form on the surface. These tints may also form when there is a fine surface coat that has been applied on the surface of the object.	Other than altering the stainless steel look of the object, there is no other negative effect of the iridescence.
BIOLOGICAL GROWTH			
Image	**Term and Description**	**Probable Cause & Mechanism of Damage**	**Effect**
	**Microbiological growth** Green deposits on metal surfaces such as on aluminum can be seen on sculptures exposed to open air or in gardens, and under trees.	Microbiological growth including cyanobacteria or blue-green algae can colonise aluminum surfaces.	If not removed, microbiologically influenced corrosion (MIC) might commence on the object. It often leads to removal of the protective aluminum oxide layer paving the way for further corrosion such as due to chloride rich atmosphere in coastal zones.