

Colouring Stainless Steel



Euro Inox

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- European stainless steel producers;
- national stainless steel development associations;
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The prime objectives of Euro Inox are to create awareness of the unique properties of stainless steel and to further its use in existing applications and in new markets. To achieve these objectives, Euro Inox organises conferences and seminars and issues guidance in printed and electronic form, to enable architects, designers, specifiers, fabricators and end users to become more familiar with the material. Euro Inox also supports technical and market research.

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Steel Color S.p.a., Pescarolo Ed Uniti (I) (left)
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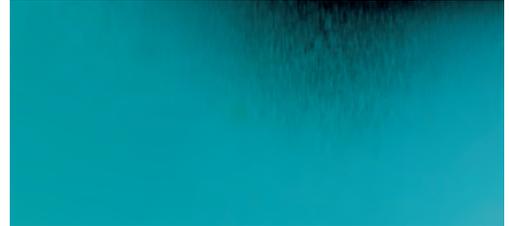
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1 Introduction

When stainless steel is specified, there is no reason to limit the colour choice to silver. A wide range of both opaque and translucent colours is available. The underlying finish texture can remain visible and add to the aesthetic appeal. Stainless steel's superior corrosion resistance makes coloured stainless steel an excellent, sustainable material choice for demanding applications [1].

Stainless steels are a family of materials with a unique set of properties. Protected by a passive film at the surface, formed by a reaction between the chromium in the steel and the oxygen in the atmosphere, stainless steels require no additional surface protection against corrosion, as long as the type selected is suitable for the environment. If the original surface is damaged by accidental scratching or deliberately abraded during finishing, the film immediately self-repairs in the presence of oxygen. As this publication explains, the protective layer can be modified by chemical processes to produce metallic colours. The layer can also be hardened by electrolysis.



The controlled thickening of the passive film produces light-interference effects, which are perceived as colours.

2 *Electrochemical colouring*

It has long been known that stainless steel surfaces can be coloured by treatment in a hot solution containing chromic and sulphuric acids or in a hot alkaline solution containing oxidizing agents. Many trials were carried out for commercializing the processes but coloured film obtained in this way proved too soft and porous to give adequate wear and abrasion resistance [2].

The initial breakthrough in colouring stainless steel occurred in 1972, with a colouring method known as the Inco-process, which is based on the anodic electroless deposition of chromium oxide.

Several proprietary variations on this process for colouring stainless steel have since been developed, involving immersing the material in a hot chromic-sulphuric acid solution and following this with a cathodic hardening treatment in another acid solution. It does not apply any additional layer containing pigments or other colouring agents which might impair the properties of stainless steel. The colouring process chemically thickens the passive chromium-oxide layer that gives stainless steel its corrosion resistance. The colours are produced by the interference that occurs as light waves pass through the transparent passive layer [3].

Austenitic stainless steel is particularly suited to this electrochemical or interference colouring process. The immersion time of the steel in the acid solution determines the thickness of the surface film, the light wave interference (or filtration) and the intense reflected colour effect – similar to the rainbow interference effect of soap or oil on a



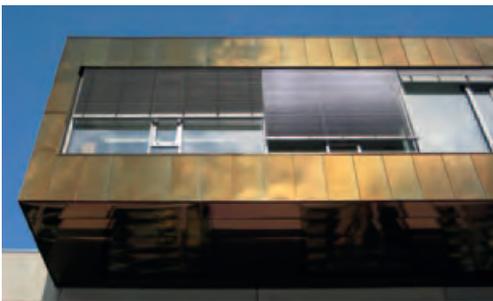
surface. The specific range of colour effects the film passes through (bronze, gold, red, purple, blue and green) corresponds to an increase in the film thickness from $0.02\ \mu\text{m}$ to $0.36\ \mu\text{m}$. Ferritic stainless steels can only be coloured dark grey by this process.

Kiosks clad with coloured stainless steel can be found in the tourist hot spots of Vienna.

Gold-coloured stainless steel gives a touch of luxury to lobby areas. Photo: Steel Color, Pescarolo Ed Uniti (I)



The apparent colour changes according to the angle of light.



Being colourless, the chromium oxide layer is not susceptible to fading by ultraviolet light and, as the colouring process does not involve pigments, fabrication can be carried out after treatment without the film cracking. In bending, for example, the inert film will thin at the bent edge, marginally reducing the depth of colour [4].

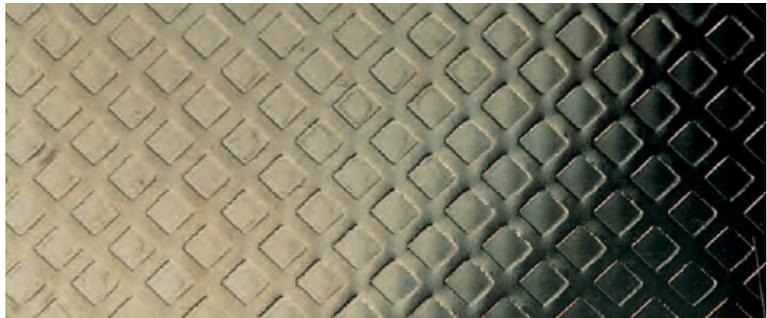
Colour can be applied uniformly or deliberately varied for a rainbow effect. There will be slight variations in colour and for larger surfaces, it is important to obtain samples that illustrate the range of colours. Because the colour depends on the way light is reflected through a transparent passive film, the angle at which the surface is viewed can change the apparent colour. For the same reason, curving or forming the panels will also change the apparent colour of the stainless steel. This should be considered during design. The colour variation achieved by curving larger panels can be

used as a design element [1]. If a very uniform colour is desired over a large curved surface, then small flat panels are used to segment the surface and make its appearance as uniform as possible.

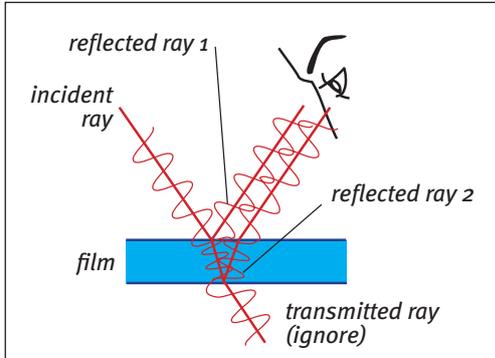
As the passive surface film is transparent, the underlying substrate finish will influence the final appearance. For example, a dull finish will result in a subdued, matt colour while a mirror polish will give a brightly-coloured appearance. Unlike painted surfaces, the colour will not fade over time with exposure to sunlight. However, if the surface is damaged by scratching, fabrication or corrosion, it cannot be repaired [4].

The colour can also be removed by abrasion, so it should not be used where accidental or deliberate damage can occur, such as in a high-traffic area or where there are wind-blown abrasives [2, 5]. Pickling, etching and electropolishing will remove the coloured surface.

Stainless steel coloured by this process cannot be welded without destroying the surface. Because of this heat damage, welding and brazing should be avoided or performed on out-of-sight areas. With special solders and fluxes, some soldering can be performed on coloured surfaces. Adhesive bonding can be applied without restriction, as long as curing temperatures are not too high. Screwing, riveting and clamping are suitable mechanical fastening methods [3].



The original surface and its degree of reflectivity are unaffected by electrochemical colouring.



The principle of light interference

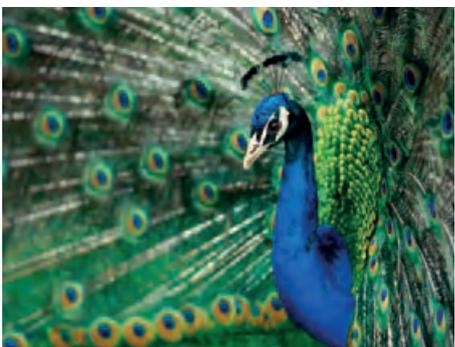
Rays 1 and 2 interfere

The wavelength inside the film is shorter:
 $l' = l / n$
 $n =$ the index of refraction of the film

Ray 1 suffers a phase change of 180 degrees



Light interference in soap film



The iridescence of peacock feathers is caused by light reflected from a complex layered surface.

Source: <http://www.mwit.ac.th/>

2.1 Corrosion resistance

The corrosion resistance of the coloured surface depends on the stainless steel specified. The process strengthens the passive layer, so electrochemically coloured stainless steel will show a higher initial resistance to pitting corrosion than uncoloured surfaces. Research has shown, however, that this slight improvement does not significantly affect long-term performance [6]. If a type of stainless steel is likely to exhibit corrosion in a given service environment, this will also occur on the coloured surface. Unlike uncoloured finishes, where light corrosion staining can generally be removed without adversely affecting the appearance, even light corrosion of coloured surfaces can cause permanent colour change. Removal of the corrosion product will also remove the colour. The stainless steel to be coloured should therefore be selected so that no corrosion will occur in environment to which it will be subjected [3]. Literature is available giving guidance on appropriate stainless steels for architectural applications [7, 8].

As shown in Table 1, short-to-moderate exposure to common foods and construction chemicals will not change the appearance of electrochemically coloured stainless steels.

Any surface corrosion will permanently remove the colour from the affected area, so great care must be taken to select a stainless steel chemistry that will provide corrosion-free performance.

Table 1: Corrosion resistance of coloured 1.4301/304 to various chemical agents [2]

Agent	Conc. (%)	Temp. (°C)	Time (h)	Colour		
				Green	Amber	Black
Cement water	-	50 100	50 10	∅ □	∅ □	∅ □
Sodium carbonate	5	50 100	50 10	∅	∅	∅
Caustic soda	5	50 100	50 10	∅	∅	∅
Detergent (neutral)	5	50 100	50 10	∅	∅	∅
Acetone	100	RT	200	∅	∅	∅
Lacquer thinner	-	RT	200	∅	∅	∅
Trichloroethylene	-	RT	200	∅	∅	∅
Soybean sauce	-	100	10	∅	∅	∅

∅ No change in colour □ Slight change in colour



Electrolytically coloured stainless steel surfaces are exceptionally UV resistant. Photo: Rimex Metals, Enfield (UK)

At the Reiyuuka Shakaden Temple in Japan, electrochemically coloured stainless steel has performed well since 1975. Photo: Nickel Institute, Toronto (CA)



2.2 Light and weather ageing

Since there are no pigments or colouring agents that might bleach or fade, coloured stainless steel has a long life in terms of environmental exposure. The colour will not fade when exposed to sunlight or weather. It is reported that there is no colour change in electrochemically coloured roof panels even after 30 years [1]. Furthermore, the coloured surface does not crack or peel and will resist ageing [3].

2.3 Applications for electrolytically coloured stainless steel

A particular attraction of coloured stainless steel is that it appears to change colour under different lighting conditions and angles, in both artificial and natural light. It is important to ensure that a good match is achieved between sheets intended for multiple-panel features. Applications for coloured sheets and panels include architectural external cladding (facades, columns, roofing, etc.), internal cladding in low-traffic areas, signs, shop display panels and sculptures.

Coloured stainless steel cannot be repaired if scratched and is therefore best suited to applications where scratching and abrasion are relatively unlikely [9].



Coloured stainless steel highlights the three-dimensional geometry of the Banca S. Marino building. Photo: Steel Color, Pescarolo Ed Uniti (I)

The facade of the Brand Loyalty building, Eindhoven (NL), was constructed using the standing seam technique traditionally used for roofing. Photo: Rimex Metals, Enfield (UK)



3 *Surface blackening*

Stainless steel surfaces can be readily blackened by immersion in a molten salt bath of sodium dichromate. This practice, which is relatively simple to set up and operate, is widely used by the automotive industry to blacken stainless steel parts (such as windscreen wipers) and by manufacturers of stainless steel solar-collector panels.

The process, applicable to any stainless steel type, results in the development of a very thin, smooth, black oxide film on the surface of the steel. The film is normally dull black but can be brightened by the application of oils and waxes. It shows no tendency to age or lose colour in service. It is ductile, will not chip or peel and is resistant to heating, up to the normal scaling temperature of the stainless steel. A blackened stainless steel can be moderately deformed without harm and the film exhibits good resistance to abrasion. It may be removed by corrosion and particularly heavy abrasion.

The salt bath operates at approximately 400 °C and dip time (varying from 5 minutes to 30 minutes) is followed by washing with water. Solar panels achieve an ideal blackening in 5 minutes, whereas auto trim parts take about 30 minutes to acquire a deeper black colour [16]. The process has also been used for smaller architectural components and flatware handles where a more scratch-resistant black than can be achieved with electrochemical colouring is desired.



Absorber plates of solar hot-water panels can be made from blackened stainless steel. Photos: Energie Solaire, Sierre (CH)



Surface-blackened stainless steel is widely used for windscreen wipers and decorative parts of motorcycles. Photo: Steel Color, Pescarolo Ed Uniti (I)

4 PVD coatings or sputtered colour



PVD coatings produce hard and scratch-resistant surfaces.

Because physical vapour deposition (PVD) coatings allow a full spectrum of colours to be achieved, they are a popular option for aesthetic effects in applications such as large metal panels, taps, door hardware, glass-door frames and consumer products. Vapour-deposited coatings are also widely used for industrial and consumer applications. The surface has greatly improved wear, friction and hardness properties and the coating also provides very consistent, uniform, long-lasting colour. Unlike the electrochemical process, the surface colour will not change with the viewing angle. It is also much more scratch resistant.

Physical vapour deposition (PVD) is a general term used to describe a family of processing methods by which thin films are deposited onto surfaces (such as metal sheets, cutting tools, fasteners, glass, semiconductor wafers and even consumer-product packaging). The coating material is vaporized then deposited on the substrate surface. A variety of methods can be used to melt and vaporize the coating material, including high-powered cathodic arc, lasers, high vapour pressure

and plasma discharge bombardment (sputtering). These vapour particles then move across a vacuum chamber filled with an inert gas, typically argon, to be deposited on the substrate. The term PVD was first used in 1966 but Michael Faraday used this process to deposit coatings as early as 1838.

Figure 1 shows a diagram of the sputtering process. In its simplest form, the process occurs in an inert (noble) gas at low pressure (0.1–10 Pa). Sputtering begins when an electrical discharge is produced and the inert gas, often argon, becomes ionized. The low-pressure electrical discharge is known as glow discharge and the ionized gas is called plasma.

The argon ions hit the solid target – which is the source of the coating material, not to be confused with the substrate, which is the item to be coated. The material is dislodged from the target surface through momentum energy exchange. Sputtering is the best technique for depositing thin films. Deposition can be achieved in a controllable manner, adhesion is good and the quality, structure and uniformity of deposits are excellent [10].

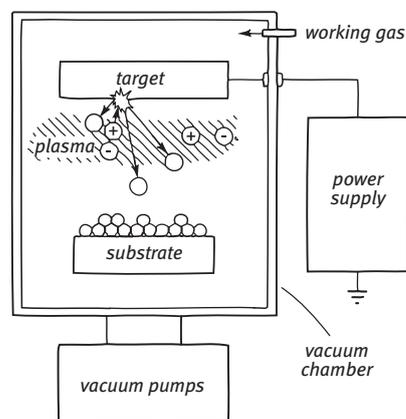


Figure 1: Diagram of the sputtering process

The surface layers are ceramic, not metallic, in nature. The colours that can be obtained using this process include gold, rose-gold, bronze, blue, black and wine red. Since the coating is very thin (typically $0.3\ \mu\text{m}$), the texture of the underlying finish is visible. It is not unusual for finish suppliers to apply patterns, by etching, polishing or engraving, prior to coating the surface. Although it has been used for aggressive applications such as door hardware, it is important to note that the colour can be damaged if it is attacked aggressively. This damage is not repairable [1].



PVD coatings have the advantage that the film (if sufficiently thick) is essentially pore-free and fully dense. Penetration to the substrate by moisture and gases is therefore greatly reduced, if not eliminated [10]. However, if the stainless steel is to be bent or formed during fabrication, it is important that product acceptance should be subject to a bend test on receipt of the material.

Making a tight bend on a small piece of metal is all that is required to determine if there is a problem with surface adhesion. If there are processing problems, the coating may delaminate during bending or impact. This should not usually arise with a high-quality supplier.

If welding is needed, this should be done prior to applying the ceramic coating [1].

Decorative metal sheets with a PVD layer are often used for elevators and column covers where pedestrian traffic can be expected [11].



Sputtering can produce ceramic surfaces, which are exceptionally wear-resistant.

Photo: Inox-Color, Walldürn (D)

PVD coatings are available in various colours.
Photos: Hans Hollein Atelier, Vienna (A)



5 Coil coating

Coil coating is an established process of in-line colouring of stainless steel coils, usually carried out by a steel manufacturer or by specialised companies. It provides an extensive colour range and allows clear varnishes (anti-fingerprint surfaces) to be applied.

Prior to coating, the stainless steel is chemically cleaned and rinsed. The steel substrate can be either austenitic or ferritic and coatings can be optimised according to specific functions and to the in-service environment. Primer and finish coatings are applied by roller to the surface of the stainless steel, in its coil form, on a continuous coating line. The prepared surface receives a prime coat, which is cured by convection-oven baking, prior to applying the finish coat. Various coatings are available for different applications, environments or service conditions. Coil coated material can be used successfully in highly demanding environments such as high-traffic road tunnels, for example, which are often poorly ventilated and characterised by high humidity and a high concentration of polluting gases from car engines.



An attractive, red stainless steel finish in the Piazzale Carlo Maciachini metro station in Milan.

Photo: Centro Inox, Milan (I)

The colours applied do not increase the corrosion resistance of the stainless steel as the substrate material. Stainless steel's intrinsic corrosion resistance is however fully used, especially on the unpainted reverse side, in the case of scratches and damage to paint and on the edges. Contrary to traditional materials (e.g. galvanised painted steel), stainless steel coil coated materials are immune to blistering and delamination on cut edges [12]. If paint is applied, it is not for corrosion protection, but for aesthetic reasons or for its non-glaring or anti-fingerprint properties.



Both clear and opaque coatings can be applied to stainless steel.

Photo: Replasa, Astrain, Navarra (E)



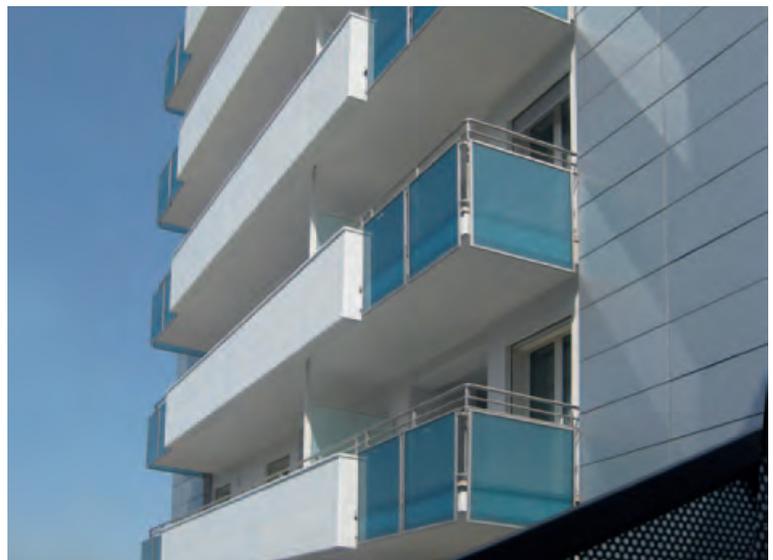
In corrosion-resistant tunnel liners, coil-coated stainless steel is used to avoid glare. Photo: ThyssenKrupp Acciai Speciali Terni, Terni (I)

Coil coated material is non-weldable, but joining material by adhesive bonding is very successful [13]. When the edges of sheets are unpainted, the welding method is similar to that of unpainted stainless steel. Otherwise, some simple rules have to be followed [12]:

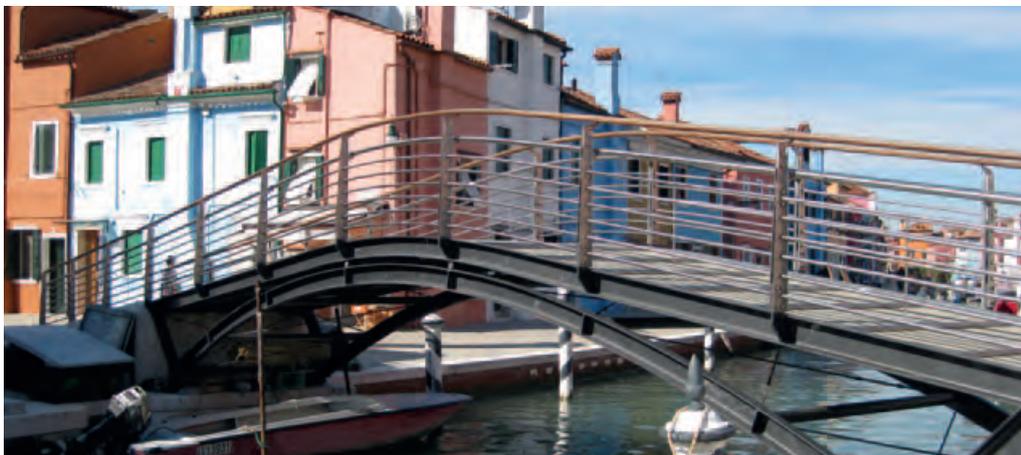
- Laser and plasma welding can be carried out without any particular precaution. It is not necessary to leave the edges unpainted.
- Mechanical shaving of the paint around the zone to be welded is recommended when using resistance (spot) welding.

Coatings are available in wide range of colours and are used in applications, such as domestic appliances, furniture, architectural panels, decorative panels, cold-storage rooms, air conditioning, metallic doors and lighting [14, 15]. Accurate colour matching can be achieved with this process due to very strict control of process parameters in the industrial production route. Suppliers generally stock the most popular colours, but virtually any colour is available providing that minimum order quantities are purchased.

Coil coated stainless steel can be bent – for instance into facade elements. Photo: Centro Inox, Milan (I)



6 Painting



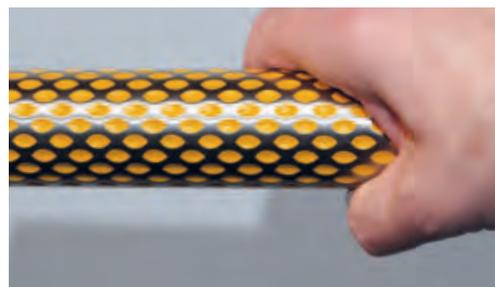
This stainless steel bridge in Venice was painted black to blend with the historic environment. Photos: IMO, London (UK)

Painting stainless steel is similar to painting other metals, except that it is done for aesthetic reasons rather than for corrosion protection. When painting is considered for new objects, it should be kept in mind that the stainless steel substrate is much more resistant to environmental factors than the paint. Decision makers should therefore consider what will happen after the paint coating eventually fails. Some projects are repainted and in some cases, the owners choose to remove the remaining paint and expose the bare stainless steel.

The greatest single cause of paint failure is loss of adhesion, leading to unattractive peeling and possibly to corrosion, due to improper surface preparation, when the surface is not correctly cleaned and pre-

treated. Care must be taken prior to any painting job to ensure that the surface is free from salts, pollutants, oil, soil, rust, corrosion products and other particulates. The surface must be sufficiently rough to allow good adherence and stainless steel has the additional requirement that since the passive film can prevent proper adherence, it should be removed shortly before painting. Stainless steel surfaces are hard and smooth, particularly when they are cold rolled or have a particularly smooth finish. When surface roughening is needed, pickling, acid etching, abrasive blasting or wire brushing is used. A suitable metal primer (etchant primer) and paint system should be applied as soon as possible after surface roughening, before the passive film has time to reform.

Colour makes stainless steel handrails easier to detect for people with impaired vision. Photo: Rimex Metals, Enfield (UK)



Several types of abrasive blasting are used. Shot peening increases surface roughness but should only be considered for heavier sections, such as structural components and plate, which will not distort from the impact of the shot. It is best performed with clean, hard, non-ferrous particles of relatively small grit size, driven by an air blast entirely free of compressor oil. Glass beads are also sometimes used. It may be possible to avoid distortion in thin-gauge material by using a backing but this should only be attempted by experienced companies.

Paint companies are best qualified to suggest paint types and procedures for primer and finish coats. A metal primer (etchant primer) suitable for stainless steel can be used to remove the passive film on a finish that is already sufficiently rough. Hot rolled mill finishes, 2B and 2D surface finishes and rougher polished finishes such as a 2G or 2J (No.4) have been painted successfully. The passive film, however, must still be removed. Cleanliness is a key element in painting stainless steels. The surface must be clean and it is good practice to paint only in a clean, dust-free atmosphere. It is advisable to use thin coats and allow a long drying time between coats [16].

Painting is often desirable to enhance visibility. Photos: Centro Inox, Milan (I)



7 Metallic coatings

Primarily used for roofing and rainwater goods, metallic coatings have also been used for exterior wall panels [17].

Tin-coated stainless steels weather to a medium-grey to dark-grey tone or can be purchased pre-weathered. They can all be damaged by scratching or abrasion but this will not affect the substrate's corrosion resistance. The final colour is dependent on the service environment. In contrast to carbon steel, metallic coatings on stainless steel are not applied to improve corrosion resistance.

A tin layer greatly improves paintability. In the case of roofs and rainwater goods, there may be architectural environments in which the durability of a stainless steel solution is required but a metallic finish may not be in keeping – for example, with listed buildings. In such cases, tin-coated stainless steel can be painted, without prior surface preparation, using manufacturer-recommended primers and paints [17, 18]. This is an easier field-painting process than painting bare stainless steel since there is no need to remove the steel's passive film.

Tin-coated stainless has been used successfully in roofing and rainwater drainage for decades.

Photo: Aperam, Luxembourg (L)



The galvanic process can also be used to apply a thin copper layer to stainless steel.

Photo: Roofinox, Schaan (FL)



8 *Cleaning coloured and painted stainless steel*

Although the substrate will have the intrinsic robustness of stainless steel, the colouring system will be more delicate. Abrasive cleaning techniques sometimes used for bare stainless steel are not suitable for coloured or painted stainless steel.

It is only possible to make general observations about the maintenance and cleaning of painted stainless steel. Specific advice must be sought from the material suppliers or from competent cleaning companies with experiences in cleaning electrochemical coloured surfaces. Some manufacturers recommend using mild detergent and degreasing solution used for washing motor vehicles. Paint companies often offer proprietary cleaners for their paint systems.

Because coloured stainless steel depends on a thickened oxide film, a PVD or a black oxide layer, great care must be taken during cleaning to avoid damaging the surface. “Repair” can only be achieved by panel replacement [19].

8.1 Initial cleaning

It is assumed that the surface will have been protected during delivery, on-site storage and erection.

It is common to use adhesive-backed, stripable plastic film to protect coloured and painted surfaces. In such instances, it is vital not to exceed the recommended maximum film life before stripping. If this is not



Cleaning the side walls reveals no corrosion, despite very unfavourable conditions inside this tunnel.

Photo: Centro Inox, Milan (I)

observed, there may be a problem of adhesive retention. If adhesive is left on the surface and needs to be removed, advice must be sought from both film and stainless steel supplier or a specialist cleaning company [19]. Water-based adhesives can generally be removed without damaging painted surfaces but some adhesives require the use of solvents that can damage paint.

8.2 Routine cleaning

The cleaning regime suggested for the routine cleaning of bare stainless steel should be adopted, with special care being taken not to damage the surface. This is particularly important when dealing with any heavily soiled, coloured stainless steel. For instance, high-pressure water-jet cleaning may damage the coloured surface. Low-pressure hosing with water containing detergent is preferable. If the soiling still remains, gentle rubbing with a soft cloth or a soft-bristle plastic brush will often loosen deposits. Overall, it is advisable to seek help from the painted or coloured stainless steel producer or a specialist cleaning company [19].

8.3 Vandalism, accidents and remedial cleaning

While techniques exist to remove paint and ink marks from coloured and painted stainless steels, removing graffiti should be left to specialist cleaning companies, otherwise the surface may be irrevocably damaged.

Graffiti scratches on painted stainless steel have the same visual effect as on painted carbon steel, with the advantage that the scratch mark is not subsequently enlarged by corrosion. Whether it is possible to repaint the scratch area and restore the surface of painted stainless steel will depend on the possibility of colour matching and on the type of paint system. In the case of electrochemically coloured stainless steel, site repair is only possible by panel replacement.

Mortar and cement splashes should be washed off immediately, since alkalinity may cause discoloration of coloured finishes. If the cement or mortar is not noticed immediately, much of the hardened material may fall off the smooth surface after

it has completely dried and the remainder can be removed with low-pressure power washing and soft-bristle brushes, taking care not to abrade the surface. After the splashing has been removed, the panels must be examined for the presence of alkaline staining. If this has occurred, coloured panels will probably have to be replaced. For painted stainless steel, removing and reapplying the paint in the affected area could be considered.

It is obviously important to avoid scratching the surface, so metallic brushes or abrasive compounds should never be used. Ideally, also, iron particles should be removed, by gentle wiping with a soft cloth, before they start to rust.

Large-scale remedial cleaning should be performed by a competent, specialist cleaning company [19], with the advice of the surface-finish supplier.

Cleansers that are safe for bare stainless steel can usually also be applied on electrolytically coloured stainless steel.



9 Specifying coloured stainless steel products

Table 6 of EN 10088 – 2 [20] uses designation 2L (special finish) for coloured flat products. This restricts the starting material to cold rolled only. Only one side has to meet the agreed colour tone and surface quality. The standard does not stipulate specific colours. Colour is to be agreed between specifier and supplier.

The usual practice is that the suppliers of finished sheet products produce handy swatch samples, to aid the surface-finish selection process [9]. Larger samples illustrating the typical colour range may be obtained later for the project mock-ups and should be viewed under all expected lighting conditions. These can serve as a visual standard for the project upon agreement between specifier and supplier.



Samples should be viewed under the actual light conditions at the building location. Photo: Inox-Color, Walldürn (D)



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