Stainless Steel and the Challenge of Time

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Stainless steel is remarkable for its practically unlimited resistance to corrosion. Of all properties, it is this resistance that makes stainless steel so useful for construction. The aesthetics of the surface and the formability of the material are fascinating. The variety of our stainless steels opens up wide possibilities for architectural design. The different product forms and surface finishes available give architects virtually a free hand (fig. 1). Used either alone or in combination with glass, stone or wood, stainless steel is practically everlasting.

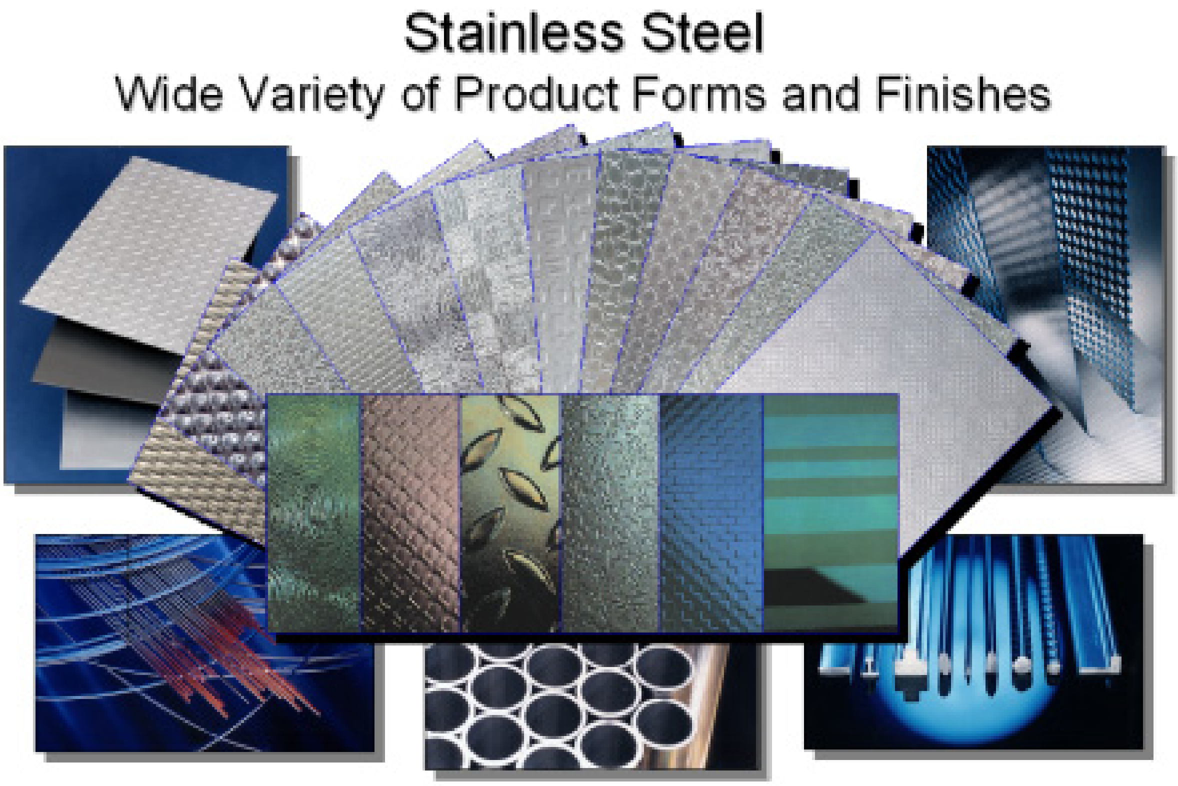


Fig. 1 Selection of product forms and surface finishes

Consumption of stainless steel has been rising steadily for years, confirming the attractiveness of this material. On the one hand it satisfies the increasing demands of high-tech industrial applications in terms of safety, quality awareness, environmental compatibility and cost.

At the same time, stainless steel is a design material that fits in perfectly with the current trend of using architecture as an expression of a modern industrial society. While the total industrial output of the OECD countries has roughly trebled over the past 40 years, stainless steel production has expanded eight-fold and continues to grow at a rate of 5 – 7% per year (fig. 2).

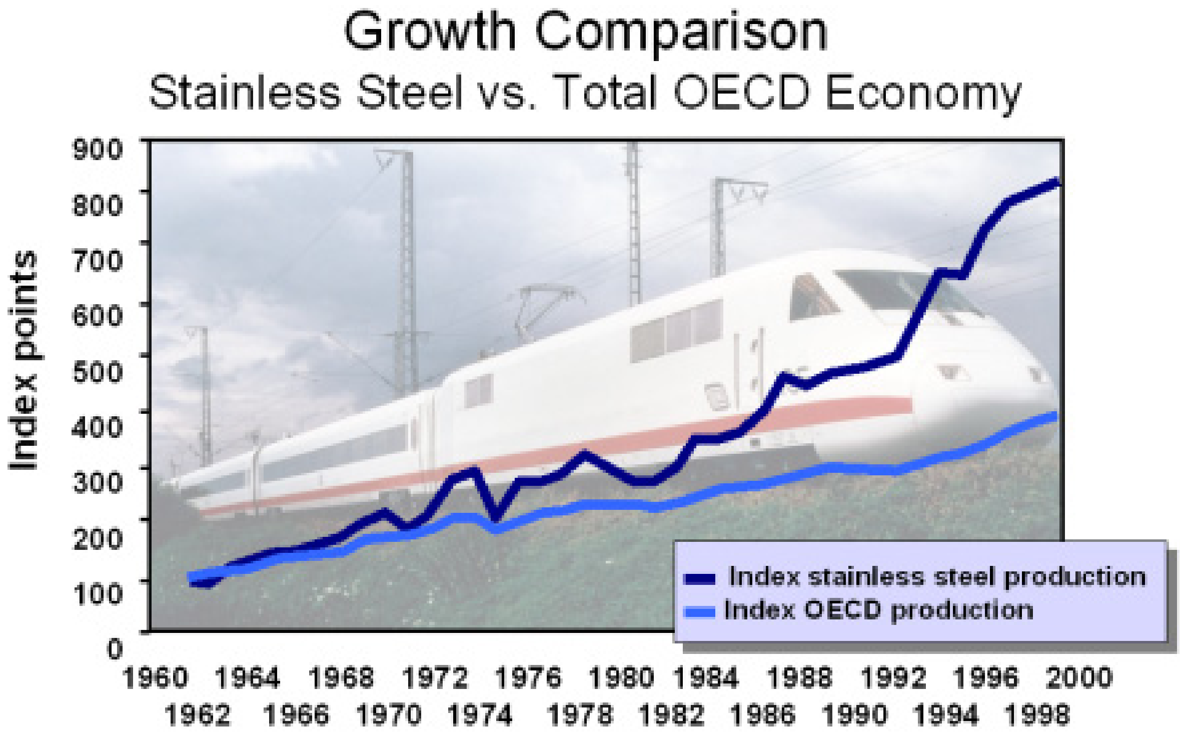


Fig. 2 Comparison of OECD and stainless steel growth rates

Although we could go on listing and describing the properties of stainless steel and developments, in this presentation we want to address a very specific area, namely the influence of surface finish on the component properties

- corrosion resistance
- reflectivity
- contamination and cleaning behaviour (fig. 3).

Numerous discussions with building owners, planners, architects and facility managers lead us to believe that there is a need for information in this area. We will discuss current knowledge levels as regards the three aforementioned stainless surface properties and will present some results of our own studies.

The Influence of Different Surface Finishes

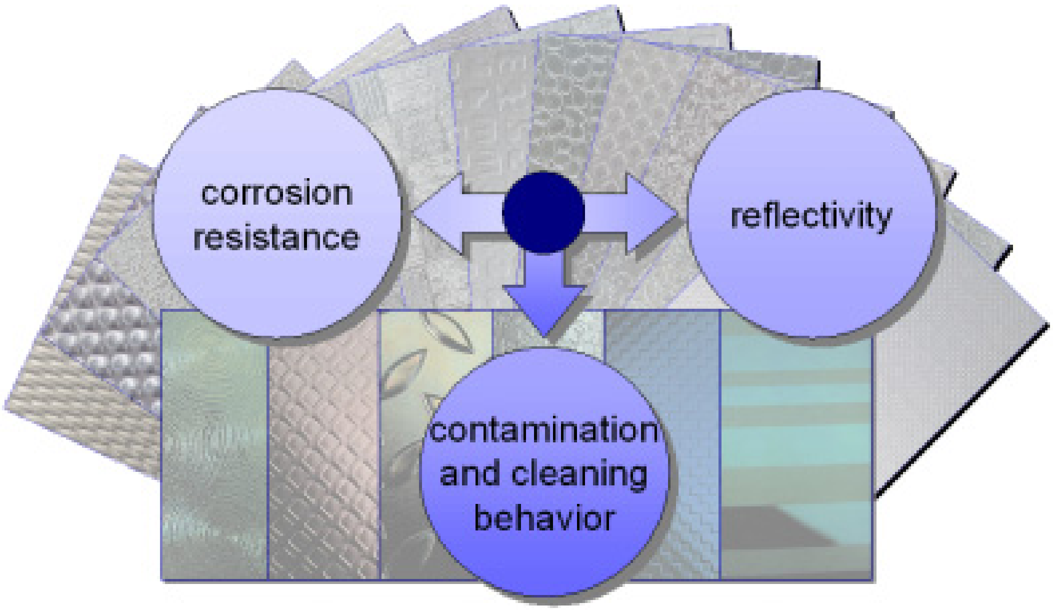


Fig. 3 Influence of surface finish on corrosion resistance, reflectivity and contamination / cleaning behaviour

First of all we would like to look at the influence of surface finish on the corrosion resistance of stainless steel. In general, architectural elements made from stainless steel are subject less to general corrosion and more to localized corrosive attack, depending on conditions. The best-known form of local corrosion on stainless materials is pitting. However, it has now been proven that pitting and other localized forms of corrosion can be avoided by selecting the suitable stainless steel grade.

Numerous studies have shown that the corrosion resistance of stainless steels increases with higher concentrations of alloying elements, in particular chromium and molybdenum (fig. 4).

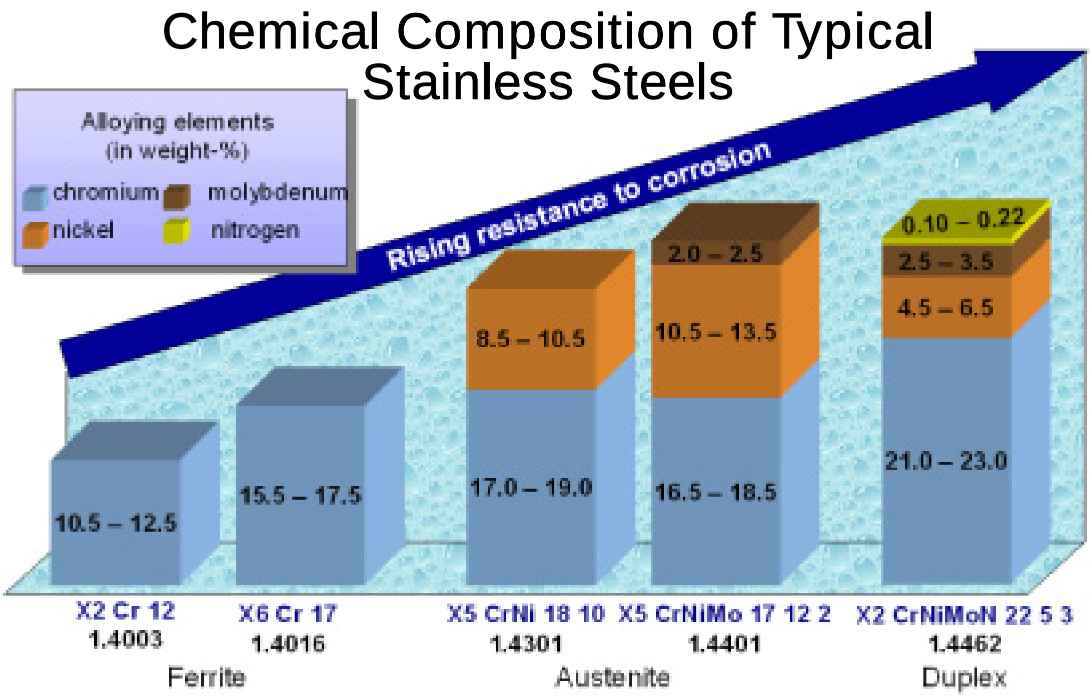


Fig. 4 Influence of the alloying element content on the corrosion resistance of stainless steel

Classification of Steel Grades According to Resistance to Corrosion

Material		Structure	Resistance class	Corrosion loads and typical applications
1.4003	X 2 Cr 11	Ferrite	I	Interior spaces
1.4016	X 6 Cr 17	Ferrite		
1.4318	X 2 CrNiN 18-7	Austenite	II	Accessible structures without significant concentrations of chlorides and sulfur dioxide
1.4567	X 3 CrNiCu 18-9	Austenite		
1.4301	X 5 CrNi 18-10	Austenite		
1.4541	X 6 CrNiTi 18-10	Austenite		
1.4401	X 5 CrNiMo 17-12-2	Austenite	III	Inaccessible structures with moderate chloride and sulfur dioxide loading
1.4404	X 2 CrNiMo 17-13-2	Austenite		
1.4571	X 6 CrNiMoTi 17-12-2	Austenite		
1.4439	X 2 CrNiMoN 17-13-5	Austenite		
1.4462	X 2 CrNiMoN 22-5-3	Ferr.-austenite	IV	Structures subject to heavy corrosion loading from chlorides and sulfur dioxide (also under concentrated loads, e.g. structures in seawater and road tunnels)
1.4539	X 1 NiCrMoCuN 25-20-5	Austenite		
1.4529	X 1 NiCrMoCuN 25-20-6	Austenite		
1.4565	X 3 CrNiMnMoNbN 23-17-5-3	Austenite		
1.4547	X 1 CrNiMoCuN 20-18-6	Austenite		

Fig. 5 Classification of stainless steels for load bearing applications

In this context we refer you to the classification of stainless steel grades in corrosion resistance categories in the German construction regulations Allgemeine bauaufsichtliche Zulassung Z 30.3-6 issued by Deutsches Institut für Bautechnik (fig. 5). This classification was made for stainless steels used in load-bearing structural members. The grade 1.4003 in corrosion resistance category 1 is a stainless structural steel with a chromium content of approx. 12%. This steel is used either coated or in absolutely corrosion-free areas. Despite displaying higher corrosion resistance than 1.4003, material no. 1.4016 is not recommended for outdoor applications.

The influence of the surface finish on the corrosion resistance of stainless steels is well known and has been documented in numerous studies. We would like to present the findings of studies carried out by our company (fig. 6). It should be pointed out that the corrosion resistance of stainless steels is influenced and guaranteed in particular by their chemical composition. Although surface finish also has an effect on corrosion resistance, this tends only to come to the fore in applications at the limits of the material's corrosion resistance; for example, a stainless steel with a ground surface may fail in a marine climate, while a component of the same grade but with an electropolished surface will not suffer any corrosion under the same conditions.

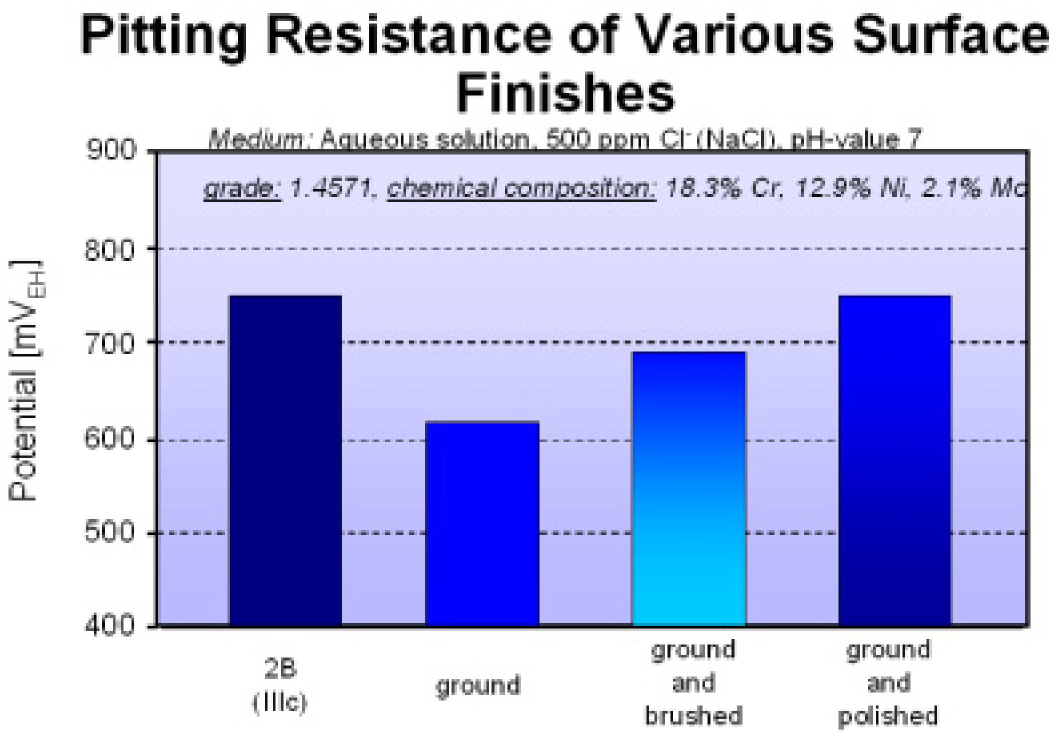


Fig. 6 Influence of surface finish on corrosion resistance

Reflectivity of various stainless finishes – General

In specific applications, a reflective “mirror” finish on stainless steel materials is desirable. Well-known applications for mirror-finish stainless steels include elevators, the foyers of representational buildings, representational counter trim panels or as mirrors in motor vehicles and aircraft, the latter due to the unbreakable nature of the material. However, many applications call for minimized reflectivity of the stainless steel or other metals, for example where strong reflection may be detrimental to air or road traffic safety. Matt surfaces are also required in many cases on design grounds. Copper and zinc, two other materials frequently used in construction, develop a highly matt patina when exposed to the atmosphere, which automatically solves the problem of reflection.

This 3 to 5 µm thick patina is formed by oxidation of the metallic surface. The oxidized layers are so thick that they take on a ceramic appearance and no longer have any metallic shine. These patinas vary depending on environmental conditions and may change over time. Under given conditions they can also be washed off. In contrast to these materials, stainless steel retains a bright metallic surface for years. The so-called passive layer on stainless steel is only a few nanometers thick. An increasingly important advantage of stainless steel in corresponding applications is that it does not contaminate effluent or ground water.

To minimize the metallic gloss or even the directional reflectivity of stainless steels, a variety of matt finishes have been developed which are available in sheet and strip form.

Before we present the measured reflection values of various stainless finishes we would like to explain some simple physical principles governing light reflection which we hope will make the gloss measurement process easier to understand. The commonly used visual assessment of facades is highly subjective and is influenced by ambient conditions, in particular light conditions.

The aim of the gloss measurement methods used today is to move away from subjective assessment to an objective, qualifiable assessment of surface gloss on stainless steels.

Metallic gloss is generally understood to be the directional reflection of light. This kind of reflection occurs on very smooth, bright metallic surfaces. The angle of incidence of the light rays α_{in} is equal to the angle of reflection α_{out} (fig. 7). Ceramic and organic surfaces display diffuse reflection, that is, the reflection of light rays striking the surface is diffused.

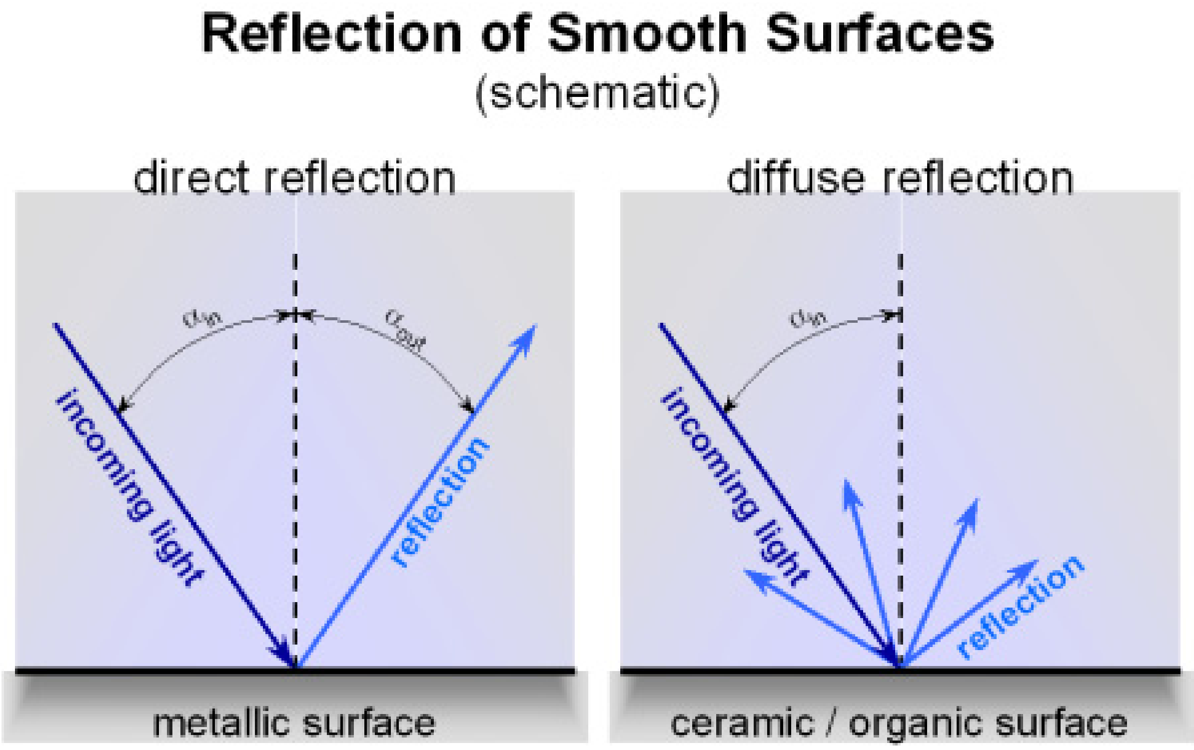


Fig. 7 Reflection on smooth surfaces

Figure 8 shows schematically the reflectivity of metallic surfaces of differing roughness.
We can summarize by saying:

Low roughness	→	low dispersion	→	high gloss
High roughness	→	high dispersion	→	low gloss

Today the reflectivity of metallic surfaces is measured using standardized reflectometers (fig. 9). Reflectometers operate on the reflection principle, that is, they measure the directional reflection of a light ray striking a surface in a defined way. In standard measuring procedures the reflecting surface is 8 mm wide and 10 to 20 mm long depending on the angle of incidence selected.

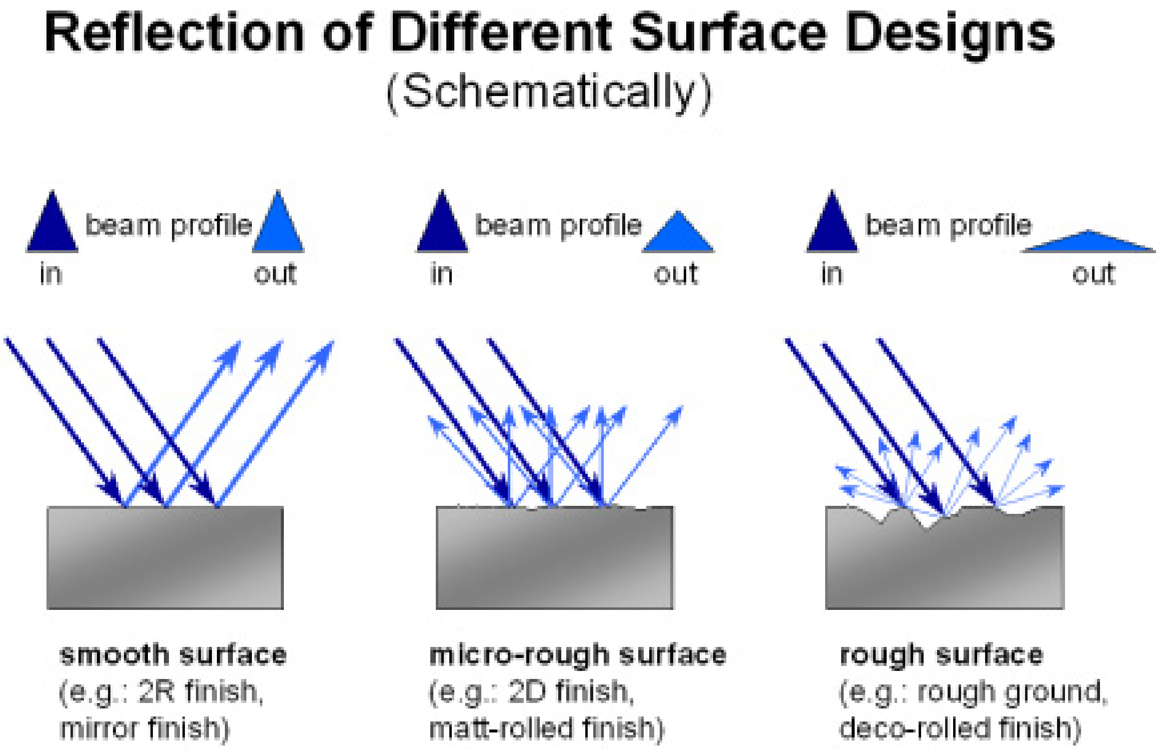


Fig. 8 Reflectivity of different metallic surfaces

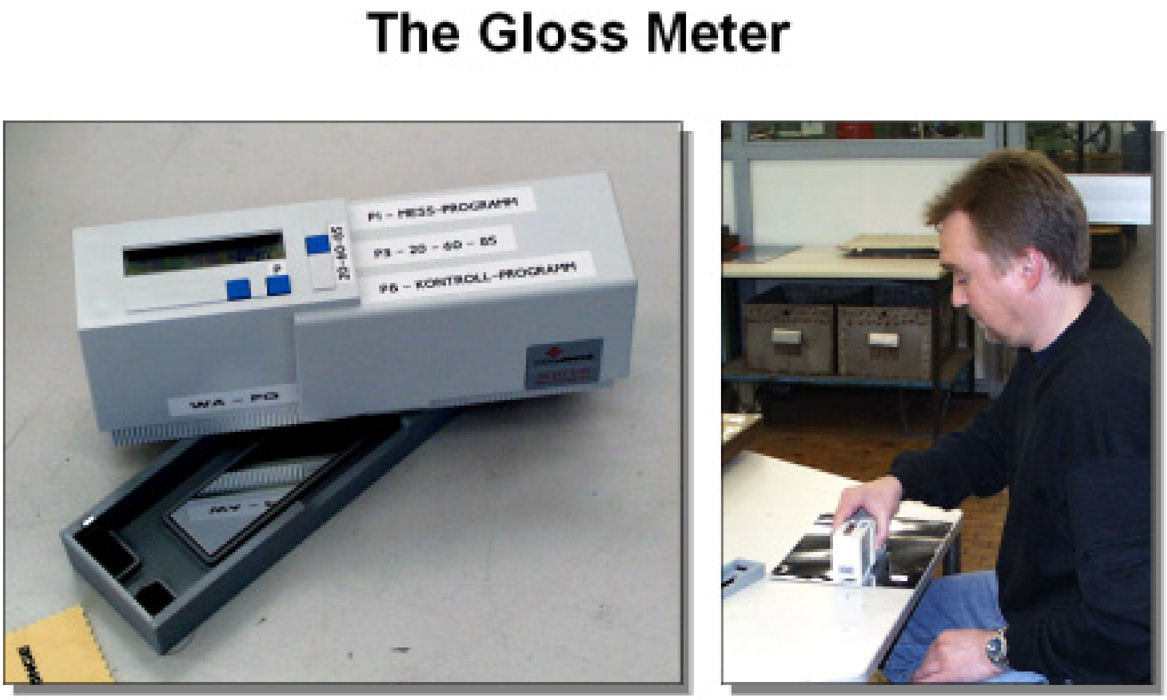


Fig. 9 Gloss meter

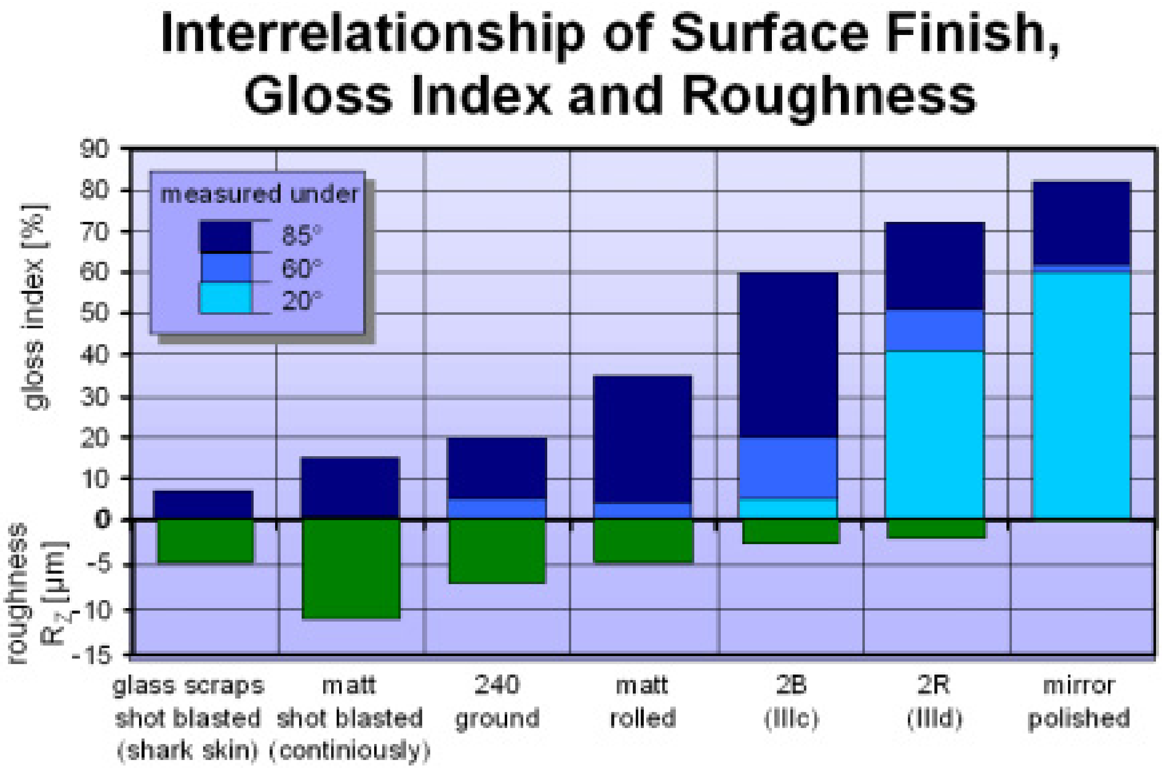


Fig. 10 Gloss index rating and R_Z values

The diagram in figure 10 shows the gloss index rating and associated roughness values R_Z measured on different stainless steel surfaces. At this point we would like to summarize what has been said so far about reflection. The aim of gloss measurements on stainless steels is to achieve an objective assessment of a surface in terms of its reflectivity. Critical examination of the specimen values determined confirms that gloss measurement with reflectometers contributes to an objective surface assessment. However, the technical measuring method cannot fully reproduce the subjective assessment of the human eye, as the latter also takes in other factors such as colour, absolute brightness values and visible surface structures to form an overall picture. The results of the measurements show that it is possible to create surfaces by low-cost industrial methods that display lower reflectivity than previous 2B finishes.

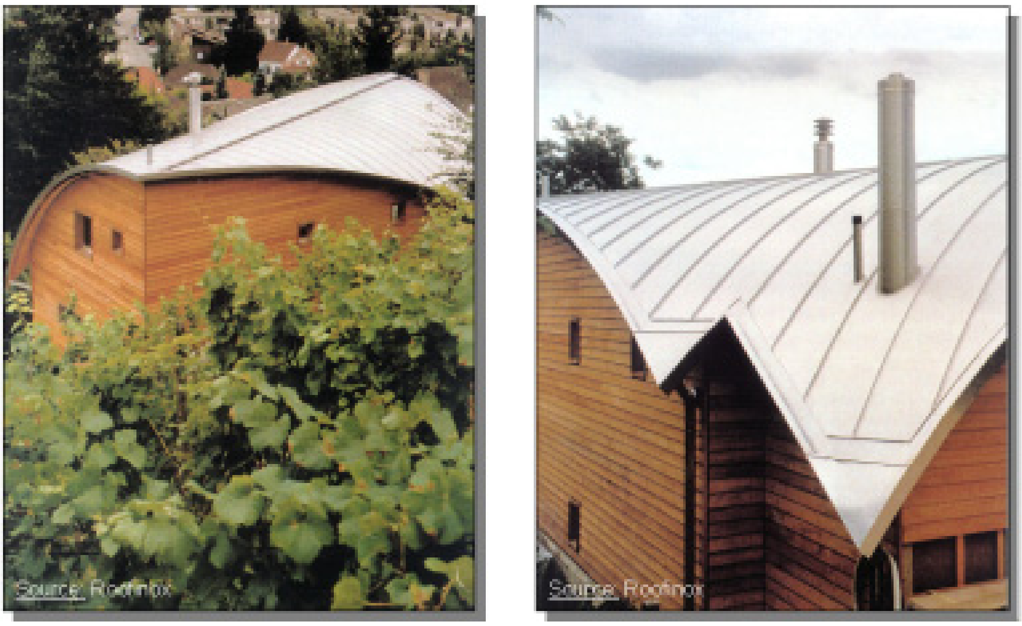
The following pictures show example applications. Picture 11 shows the Neuer Zollhof building in Düsseldorf, clad with bright annealed panels. The bright mirror finish was selected deliberately as a design feature. The building’s appearance varies depending on the light conditions and where the observer is standing. In contrast, picture 12 shows an example of the application of matt-rolled sheet with a uniform appearance.

„Neuer Zollhof“
Harbour Düsseldorf, Germany

Facade worked in bright annealed stainless steel, *Architect*: Frank Gehry, USA
grade 1.4401 in 0.5 mm thickness.

Fig. 11 Neuer Zollhof, Düsseldorf (Germany)

Residential Building in Vorarlberg, Austria



Stainless Steel as roofing material for domestic architecture.
Grade 1.4301 (AISI 304) with matt-rolled surface, thickness 0.5 mm

Fig. 12 Matt rolled finish for roofing

Contamination and cleaning behaviour

Stainless steels used in architecture have a low susceptibility to contamination and are easy to clean. Nonetheless, stains such as fingerprints can spoil the picture in some areas. There are some fundamental observations that are of significance for minimizing the negative visual impact of fingerprints. As manufacturers, we must take part in this discussion so as to enhance the acceptance of stainless steel materials in certain applications. A basic difference must be made between wetting and non-wetting surface contamination.

Non-wetting contamination includes dust, soot etc., i. e. the dirt particles lie loosely on the surface and will be washed off external facades if it rains. One impressive example of this is the roof of the Chrysler Building. An inspection some 70 years after it was built revealed the metallic surface to be fully intact and optically unchanged. The roughness which normally occurs on stainless steels, e.g. in the blasted condition, is of no relevance for cleaning non-wetting contamination. It should also be mentioned that the growth of moss and algae which is frequently found on mineral materials such as concrete, stone or wood is virtually unknown on metallic surfaces as they do not offer any hold for algae and moss.

Wetting contamination includes greasy aqueous components, human sweat, and other non-volatile fluids with which stainless steel comes into contact. As surfaces become rougher, contamination of this kind becomes more difficult to clean away, and cleaning requirements increase. This is because the wetting films of dirt penetrate or are pressed into the depressions in the rough surface.

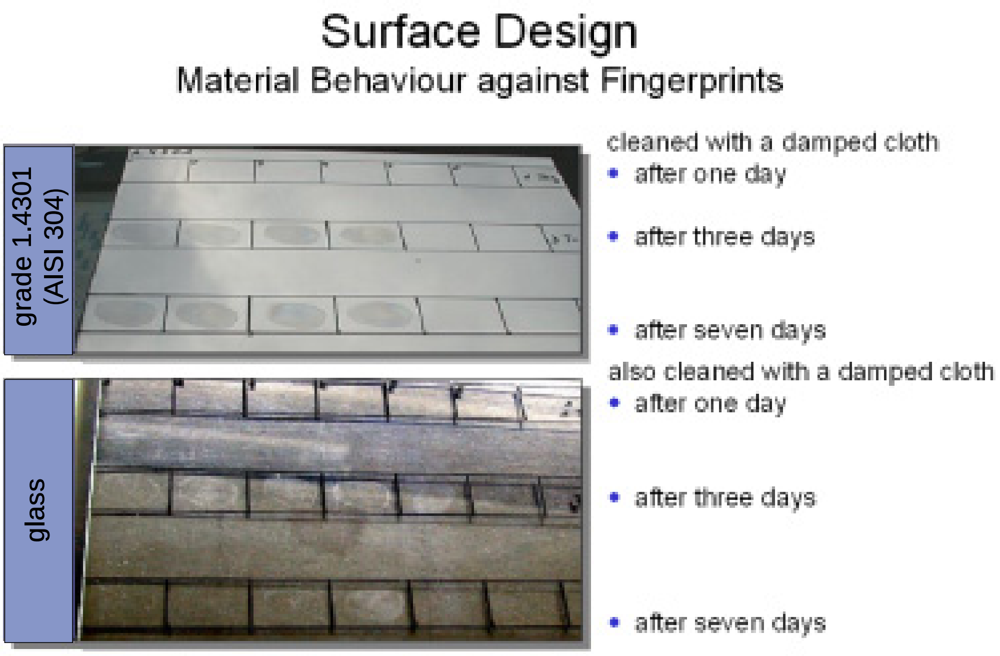


Fig. 13 Time dependence of adherence of finger marks

Experiments have shown that surfaces become more difficult to clean the longer cleaning is delayed (fig. 13). Generally this is not caused by chemical reactions between the dirt and the stainless steel surface. The same phenomenon is observed on glass surfaces, which are far more inert than metal surfaces.

The deterioration in cleanability is due to a change in the contamination, in particular fingerprints, caused by oxidation and light. Even after a lengthy period, contamination of this kind can be removed completely using grease solvents.

Remedies

Experiments have proven that the visibility of fingerprints depends among other things on the reflectivity of the surface (fig. 14). On reflective surfaces fingerprints generally appear bright. This is because the metallic surface appears dark for as long as the light reflected from it does not the eye of the observer. Contamination on the surface results in diffuse reflection of the light and these areas therefore appear bright. On non-reflecting matt surfaces fingerprints appear dark, the diffuse light is absorbed locally by the dirt layer. Between the two states there is a minimum at which by adapting the gloss the fingerprint becomes much less visible. An adapted surface can be produced for example by light glass pearl blasting. Other measures to control or minimize the nuisance effect of fingerprints are the use of pattern-rolled or not too finely ground finishes.

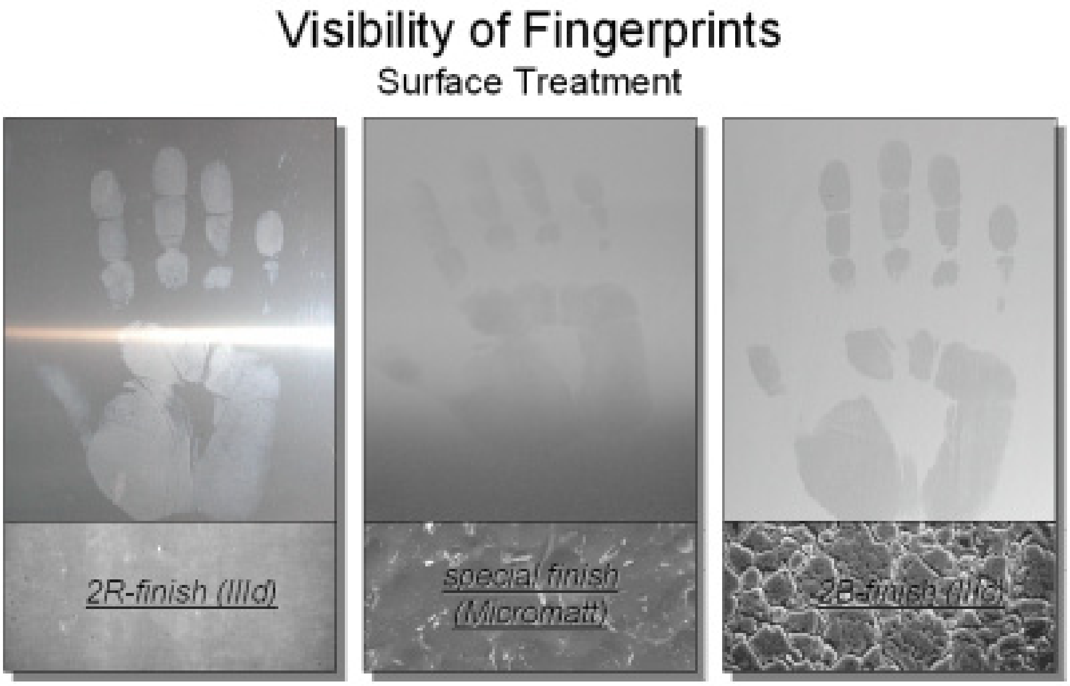


Fig. 14 Influence of surface roughness on the visibility of finger marks

We do not intend to go into any great detail about temporary or permanent coatings. Such coatings are used in indoor applications to reduce fingerprint sensitivity but they have the disadvantages of subsequent coatings that have to be re-applied. The way a temporary coating works is shown in figure 15. Here a blasted surface was half-coated with silicon oil. The surface takes on the colour of the fingerprint.

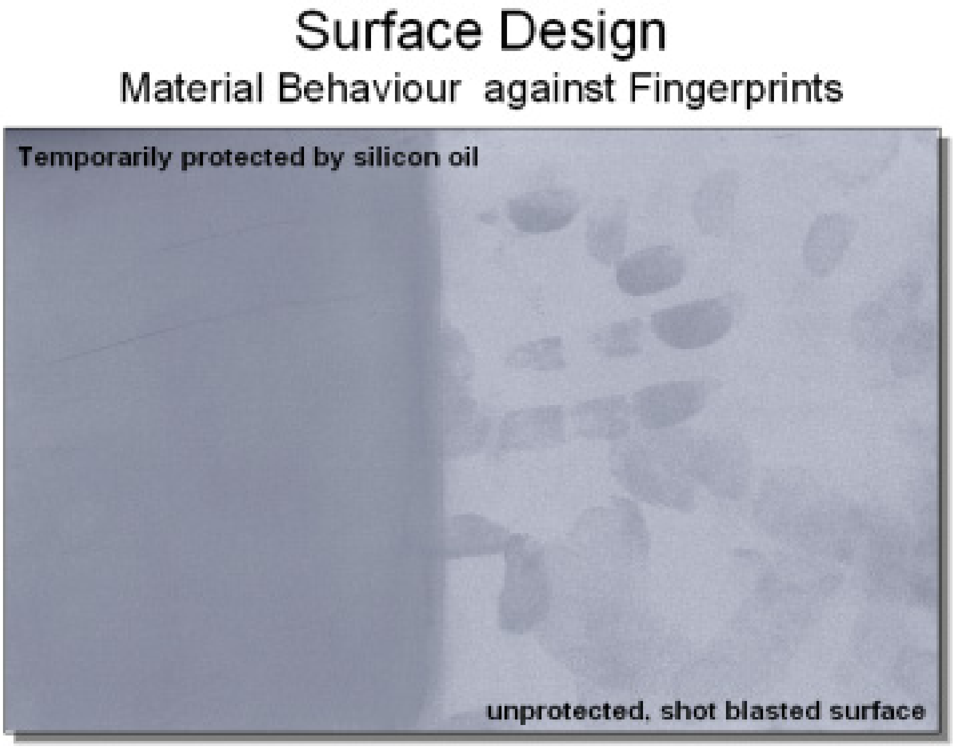


Fig. 15 Effect of temporary coatings

Our paper would not be complete without mentioning the so-called “lotus effect”, since scientists have been engaged for years in trying to apply this effect to technical surfaces. Whereas on a wettable surface the dirt particles are flooded by the water droplets and remain on the surface, in nature we observe self-cleaning surfaces, for example the so-called lotus effect on the lotus flower. This is based on an extremely fine and rough surface structure. The tips of this brush-like surface are extremely fine, in the nanometer region, and also have a water-repellent wax covering. This structure represents a fully water-repellent surface. On it, water droplets run off in globules, taking dirt particles with them (fig. 16).

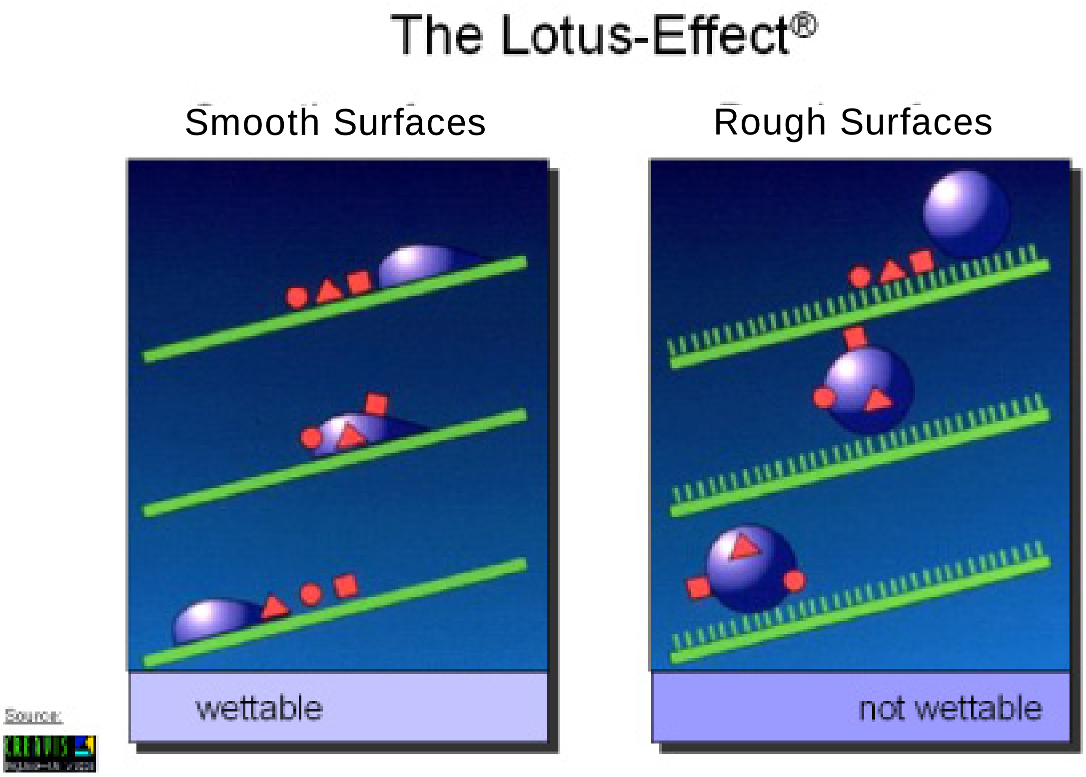


Fig. 16 Lotus effect

Such fine structures can be produced in the laboratory today but not commercially on straight metallic surfaces. The self-cleaning effect only works in conjunction with water and so would be suitable for outdoor applications. In indoor applications, however, the high water requirement for cleaning would present problems. Paints and films with an approximated lotus effect are currently being introduced to the market for outdoor applications. Lotus-like surfaces have also been produced on ceramic objects by nano-scale coatings. These surfaces are very sensitive to mechanical loading.

Summary

It has been shown that the corrosion behaviour, reflection behaviour and sensitivity to dirt of stainless steel surfaces can be influenced and optimised by appropriate "surface design". We have dealt with aspects that are of importance for the use of stainless steel in architecture. We hope that our paper will contribute to increasing the attractiveness of stainless steels in architecture and that the possibilities we have high-lighted will encourage the development of further applications for this outstanding group of materials.