Title:	**New Developments on Stainless Steel Façades with Regard to Reflectance, Corrosion and Aesthetics**
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Subjects:	Building Materials/Products Façade Design Sustainability/Green/Energy
Keywords:	Façade Steel Sustainability
Publication Date:	2015
Original Publication:	Global Interchanges: Resurgence of the Skyscraper City
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

New Developments on Stainless Steel Façades with Regard to Reflectance, Corrosion and Aesthetics

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Joern Teipel studied Physics in Bonn, Germany, and at The Ohio State University in Columbus, USA, and obtained his Ph.D. degree in 2006 in the field of nonlinear optics. He began his professional career in 2006 at a technical consultancy in Frankfurt. In 2009 he joined ThyssenKrupp Steel where he was responsible for the business development of magnesium flat products. In 2011 he transferred to the stainless steel producer ThyssenKrupp Nirosta in Krefeld – now Outokumpu. As a product manager he's in charge of all architectural applications from the technical perspective and involved in the development of new surface finishes.

Abstract

Stainless steel is a key material in modern skyscraper architecture, exploiting the material's sustainability, functionality and aesthetics. After an outline on some general features of stainless steel this article provides an overview of current façade projects in which Outokumpu acts as the stainless steel supplier. New developments of matt but lively surface finishes based on the superposition of one fine and one coarse pattern are presented. Three of these novel matt finishes are compatible with the recently revised restriction regarding the reflectance of façade material in Singapore. Furthermore, alternative grades to 316L with higher corrosion resistance are identified and their suitability to be provided with classy finishes is discussed. The article closes with an outlook on current research activities at Outokumpu which target the development of a matt and maximal omni-directional surface finish for curtain wall applications.

Keywords: Corrosion; Façade, Reflectance; Stainless Steel; Surface Finish; Sustainability

Introduction

Due to its durability and resistance to corrosion, stainless steel does not need a protective coating. This allows for an unrestricted experience of the noble appearance and the cool metallic touch. A broad array of production processes such as rolling, etching, annealing, polishing, brushing, blasting and embossing shape the surface finish of the various Outokumpu flat products. Exploitation of all these techniques provides a comprehensive portfolio of surface finishes, each with individual properties. Focus can either lay on the technical or on the aesthetical quality of the surface finish. For instance, a technical characteristic can be hard-wearing, whereas sparkle constitutes an aesthetic feature.

A dedicated team is constantly working on the optimization of current finishes and the development of new ones. New developments can either be customized finishes upon special request or entirely novel finishes with new market-demanding features.

Outokumpu brings along decades of experience producing various surface finishes with outstanding quality, consistency and exceptional properties in terms of reflectiveness and roughness. State-of-the-art Sendzimir rolling, annealing, skin-pass and tension-leveling technology allow e.g. for a homogeneous embossing depth, for perfect flatness or hassle-free formability. Most of the finishes can be produced up to a width of 1500 mm (59.1 inches) and in thicknesses down to 0.3 mm (0.012 inches).

When it comes to consulting architects and builders concerning the selection of the appropriate stainless steel grades and surface finishes for cladding projects, mainly three material features need to be taken into account: durability, mechanical performance and aesthetical appearance. The durability is primarily determined by the corrosion resistance of the selected grade. The chapter "Highly corrosion resistant steel grades with classy finishes" discusses in more detail the suitable grades for exterior architecture and their pros and cons. The mechanical performance is being defined by the interplay between material thickness and strength properties. Typical stainless steel sheet thicknesses for curtain wall applications are between 1.5 to 2.0 mm (0.06 – 0.08 inches). Concerning the aesthetical appearance it seems that a slightly damped down reflectance is currently demanded, but not at the expense of the liveliness and the metallic luster. Several developing projects were initiated last year to satisfy this market demand and the results are presented in the chapter "New developments towards surface finishes with a lower specular reflectance".

Moreover the ongoing tendency towards Green and Sustainable Building is advantageous for stainless steel. In 2014 stainless steel products by Outokumpu had an average recycling content of well over 85%. The 100% recyclability together with the low maintenance and therefore the

overall small carbon footprint plays straight into the hands of this green building material and can be rewarded with LEED MR Credits.

Considering its excellent resistance, good workability and noble visual appearance, one can summarize that stainless steel perfectly combines functionality and aesthetics.

Current Cladding Projects

This year's conference theme "Resurgence of the Skyscraper City" is reflected in the increased demand for stainless steel cladding material at Outokumpu during the last two years. Especially projects in the United States call for classy and long-lasting stainless steel façade material, as of May 2015 the sheets for no less than five buildings have been finished or are currently in production at the manufacturing site in Dillenburg, Germany, which specializes on processing highly demanding grades and surface finishes. Several further projects in the United States are in discussion just now. In Irvine, California, the curtain wall of the office building 200 Spectrum Center Drive1 by Pei Cobb Freed & Partners consumed three full coils of 316L with Linen finish which were produced in January / February this year. Approx. 170 metric tons of Linen-patterned material is required for the curtain wall of the Comcast Innovation and Technology Center2 in Philadelphia, Pennsylvania, which is designed by Foster + Partners. The major lot has already been shipped to the United States in April / May 2015 and the remaining quantity will follow in the late summer of this year. The David H. Koch Center - Presbyterian Hospital3 in New York City designed by Pei Cobb Freed & Partners will have stainless steel on the façade as well. 60 metric tons of Linen-patterned 316L were produced in April / May 2015. A Linen finish was also utilized on the podium (phase 1) of the 3 World Trade Center designed by Rogers Stirk Harbour + Partners4 in New York City. This material was already supplied in 2012. Once the decision has been made to continue the building by constructing phase 2 and 3, the challenge was to match the surface color of this new stainless steel façade with the one of the already completed podium. As all the production parameters for the podium material was carefully documented, the plant in Dillenburg was able to fulfill this requirement following exactly the same production process on the exact same production lines. In total this project will consume 550 metric tons of 316L Linen finish. Another building in the United States in Seattle, Washington, dubbed Fifth & Columbia5 by ZGF Architects requires 100 metric tons of Linen finish. This material of grade 316L will be produced in summer 2015. Another cladding project worth mentioning is Block 14 of the Amazon Headquarters6 in Seattle, Washington, designed by nbbj. The stainless steel of grade 316L with the surface finish 2B and the very dull industrially shot blasted finish called Deco Supermatt (commonly used for roofing applications and for the first time introduced on this large scale façade) was electrochemically colored by the company Inox Color in red, green and champagne (a defined color range was stipulated for each color) and then processed to curtain wall elements by Christian Pohl GmbH and Walters & Wolf. The façade is right now being paneled vertically and horizontally with these colored elements of different lengths and widths giving the façade a certain randomness, playfulness and attraction (see Figure 1).

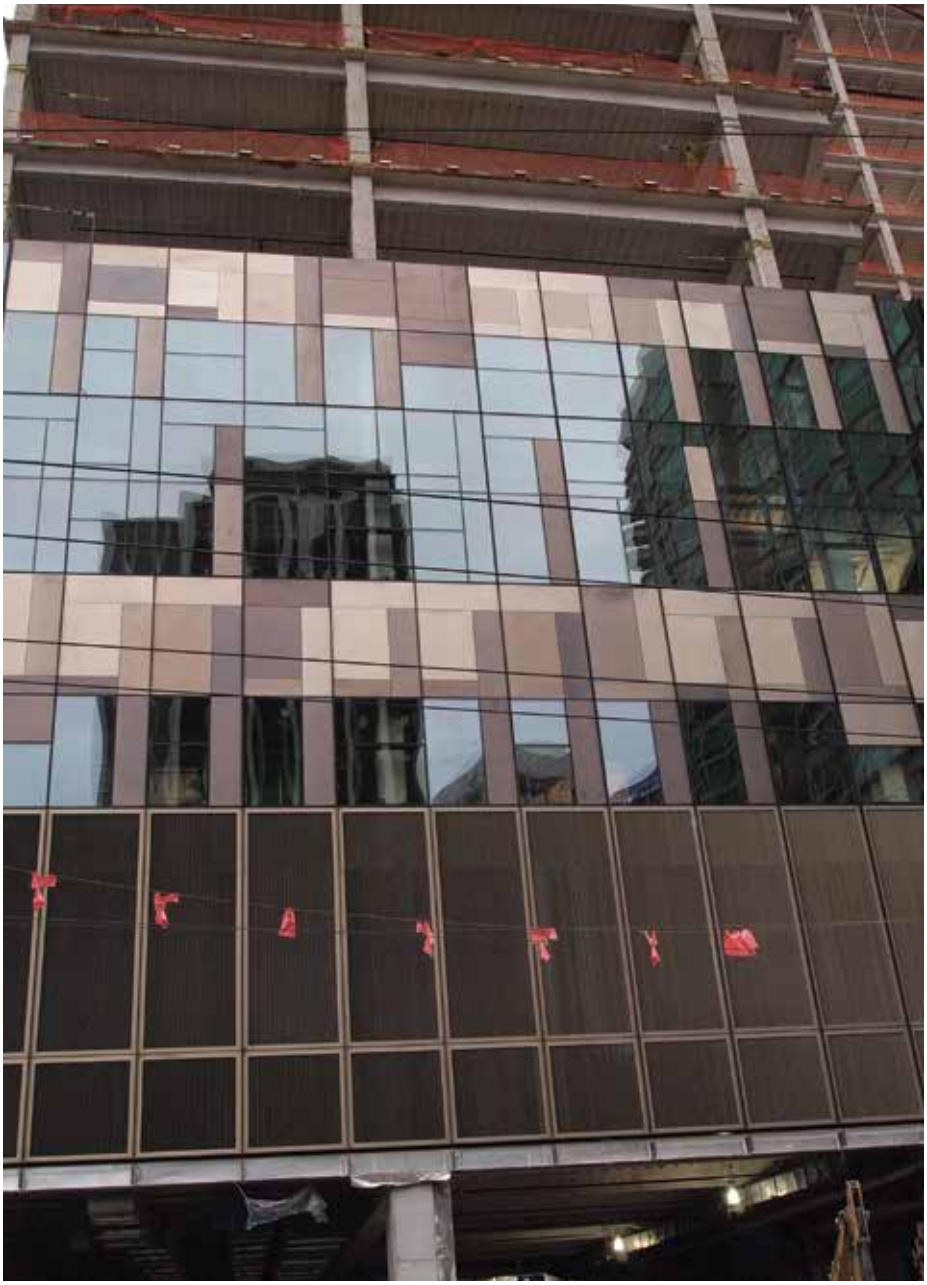

Figure 1. Installation of the electrochemically colored stainless steel panels on a corporate office building in Seattle, Washington, USA (Source: Walters & Wolf)

Figure 2. Stainless steel curtain wall on 5 Broadgate in London, UK (Source: Outokumpu)

The curtain wall of the new UBS Headquarter at 5 Broadgate7 in London, UK, by Make Architects has just been completed. In total approximately 500 metric tons of stainless steel with Linen finish and subsequently ceramic bead blasted were applied to the building. This additional bead blasting damps down the specular reflectance of the surface finish to below 10% and therefore minimizes the risks of glare of the building fronts. This galore usage of stainless steel for the façade lends the building a proud dominance within the city of London (see Figure 2) and hopefully stimulates the utilization of this material on future building projects in the neighborhood.

The world's largest stainless steel façade is to be found on the Ping An International Finance Center8 designed by Kohn Pedersen Fox. The curtain wall is currently reaching up to the 90th floor and is due to be completed at the end of 2015. Approximately 1700 metric tons of Linen-patterned 316L in total will be deployed to form the predominantly vertically oriented metal elements along the façade. The shipping of this massive quantity from Germany to China started in 2013 and the final lots will be delivered this summer / fall. Ping An is a leading insurance and financial service company in China. It is essential for these kinds of enterprises to project an image which can preferably be described by terms like "Strength", "Trust", "Power", "Security", "Pride", "Confidence" and "Honesty". When looking onto the almost completed building these qualities are equally portrayed by the stainless steel curtain wall material (see Figure 3) since steel itself is often being associated with these above mentioned values. Therefore the suggestion by KPF to choose stainless steel as the major façade material was comprehensible and very felicitous. For this powerful metallic look of the façade the surface finish indispensably must exhibit a certain degree of glossiness and brilliancy. In order to fulfill this criterion, the designers of KPF decided in favor of the popular Linen finish. This pattern resembles a textile surface and even though the human eye can no longer resolve the actual pattern from a certain distance onwards, the surface appears more uniform, consistent and classy compared to non-patterned or polished material. Approximately 25% of the incoming light is specularly reflected from the subtle Linen pattern elements leading to the desired appealing metallic glittering effect.

Updates on Statutory Regulations on the Reflectivity of Façades

Outokumpu's presentation9 at the 2014 CTBUH conference in Shanghai addressed potential glare issues of façades which were brought to attention by some media articles10, 11, 12 at that time. These incidents triggered Singapore to regulate the "daylight reflectance" (the sum of specular and diffuse reflectance in the visible wavelength range) of façade material to a maximum of 20%13,14. Last year's paper9 expounded that

Figure 3. Almost completed curtain wall on Ping An International Finance Center (April 2015) (Source: Outokumpu)

this criterion is so strict that no uncoated metal cladding (regardless if it consists of stainless steel or aluminum) is able to fulfill this regulation and that only dark colored materials will pass this restriction. As dark colored curtain walls have unfavorable effects on the energy balance of buildings and moreover will eventually result in an undiversified and gloomy appearing cityscape, the Building and Construction Authority (BCA) in Singapore eased the regulation to limits of 10% specular if 50% total reflectance is not exceeded. The criterion on specular reflectance is achievable with stainless steel in contrary to the second one. Regardless of the selected surface finish, stainless steel always totally reflects more or less 60% in the visible wavelength range. Fortunately a second revision in the beginning of this year led to a complete deletion of the restriction on total reflectance and the focus for façade material (other than glass) is now solely on the specular reflectance which was kept at 10% as the limiting value15. This regulation of the specular reflectance only was also demanded in Outokumpu's last year's paper. Although 10% specular reflectance is already a quite tough criterion to fulfill if in parallel aesthetical requirements need to be taken into account, this latest restriction now appears to be a good compromise for BCA, architects and industry.

New Developments Towards Surface Finishes with a Lower Specular Reflectance

At the last CTBUH in Shanghai it was announced that Outokumpu will tackle the subject "less reflecting stainless steel finishes"9. This feature continues to be frequently inquired by the customers, probably in part as a result of the above mentioned concern on glaring building fronts. As façade applications commonly require patterned surfaces, these research activities also focus on the modification of these types of finishes. Earlier developments of dull surfaces have shown that those finishes easily tend to appear somewhat "lifeless". Therefore the challenge in this task is to maintain the initially mentioned liveliness and sparkle that indwells stainless steel, but simply in a damped down, overall duller appearing version.

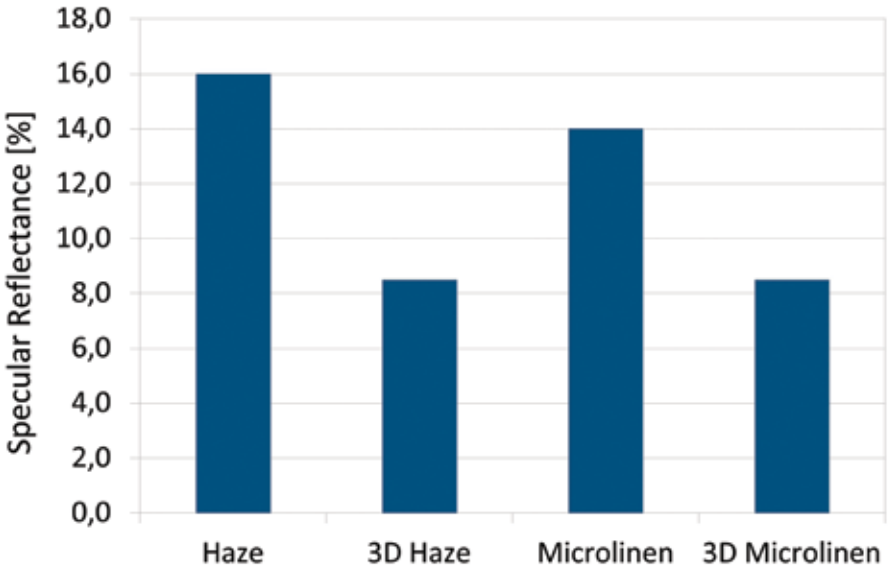

Figure 4. Decrease of specular reflectance due to additional rolling of coarse pattern (Source: Outokumpu)

Significant success has already been achieved. One solution was to superimpose a very coarse pattern on top of a fine-patterned finish. With an already low-reflecting finish as the fine pattern, a second rolling with a coarse pattern can further decrease the gloss by up to 50%. Concerning the fine pattern the Outokumpu finishes Haze and Microlinen were utilized. The course pattern can either be a so called 5WL, 6WL or a 7WL finish. For the first experiments the focus was put on 5WL and the rolling of this finish was performed by the company Schmidt Edelstahl. As the 5WL somewhat creates a third dimension to the pattern, the product was dubbed 3D Haze or 3D Microlinen according to the applied fine pattern. The measurements how the coarse-pattern-rolling affects the specular reflectance of the initial pattern are depicted in the following diagram (see Figure 4). Regular Haze and Microlinen show a specular reflectance of approximately 14 to 16%, respectively. After the 5WL-rolling the specular reflectance is dramatically reduced to 8 to 9%. Amazingly, those double-patterned surfaces prove to be a matt finish in measurement, but yet they appear smoothly sparkling and extremely lively. As the fine pattern is still almost completely intact (see Figure 5) this sparkling can still emanate from these delicate surface structures. But due to the "third dimension" added by the 5WL this sparkling becomes now more present under a larger viewing angle. Therefore the coarse pattern is responsible for this extreme liveliness. It is simply fascinating to observe the brightness spectrum when gradually tilting such a sheet by 180°. As the specular reflectance of these finishes is well below 10%, they could potentially also be utilized for cladding projects in Singapore.

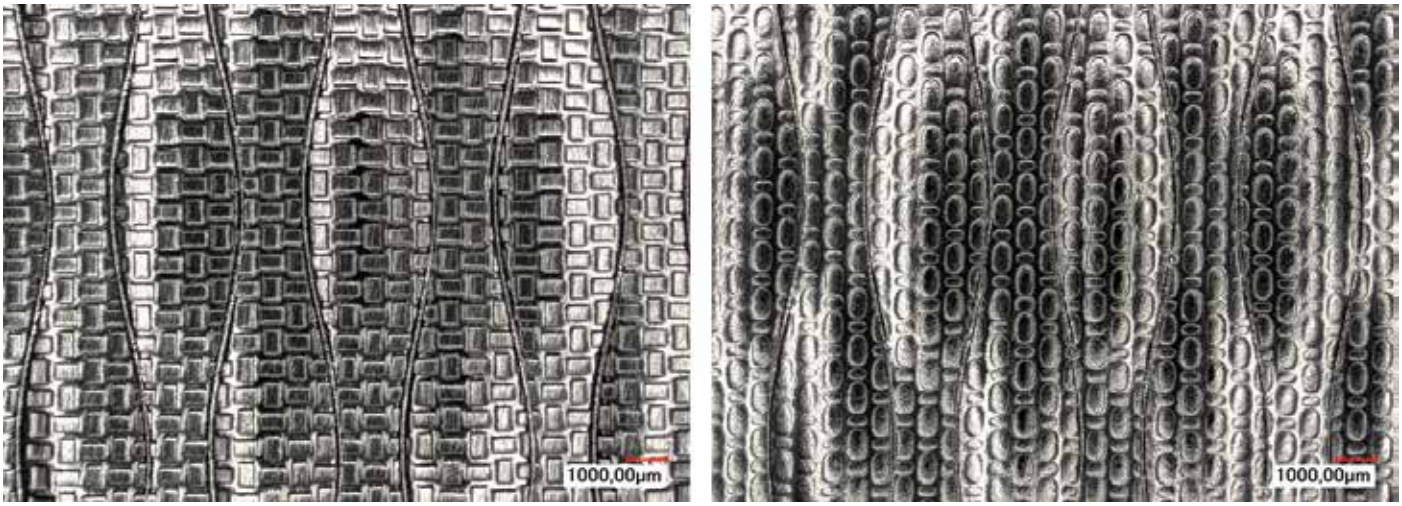

Figure 5. Microscopic images of 3D Haze (left) and 3D Microlinen (right) (Source: Outokumpu)

The next new surface development aims to offer variations of the very popular Linen pattern in terms of the reflectance. To keep the costs for those new finishes low, every process step in production needed to be applied on the coil and never on single sheets. A series of tests was performed on the available bright annealing as well as on the annealing and pickling lines and also the parameters of the rolls in different rolling and skin-pass mills were adjusted. In conclusion three new surface finishes all with lower reflectance compared to standard Linen were identified as marketable products. They were given the names Deco Linen Star, Deco Linen Matt and Deco Linen Supermatt.

Deco Linen Star

Compared to the standard Linen this high-end or premium Linen version goes through an additional production process which adds a very fine glittering sub-texture upon the pattern structure resulting in a more sparkling finish, but with an overall slightly lower reflectance alongside with a higher homogeneity of the surface.

Deco Linen Matt

This kind of product already existed before, but could be optimized applying the know-how gained within this product development. It can be described as duller than regular Linen and Deco Linen Star but it is nonetheless a lively finish due to a smoothly and slightly glittering reflectance.

Deco Linen Supermatt

This completely new finish is a symbiosis of pattering and industrial shot blasting. The result is a homogeneously dull finish with well below 10% specular reflectance caused by the rough-blasted surface structure. However, the Linen pattern nevertheless generates an unobtrusive sparkle which prevents this finish from appearing "dead" despite of its dullness. Due to the low reflectance values this finish is also an alternative as curtain wall material for building projects in Singapore.

The specular reflectance values of all four Linen versions are compared in the following diagram (see Figure 6). As the range of specular reflectance between 8% and 25% is well covered by the four Linen finishes, it facilitates the architects' choice of an appropriate stainless steel finish for the individual requirements present at a given location.

If an even more matt finish is required, the non-patterned standard Deco Supermatt finish can be applied. This finish is popular in roofing applications.

Highly Corrosion Resistant Steel Grades with Classy Finishes

At last year's CTBUH conference in Shanghai it was discussed9 that the extremely high corrosion load in the Persian Gulf region could impede outside application of the grade 316L (1.4404). Weathering tests have proven that in these harsh conditions Outokumpu Duplex Grade 2205 (1.4462) is applicable; nonetheless regular cleaning intervals of approximately once a year need to be considered. The 2205 contains approximately 22% chromium, 3% molybdenum and 6% nickel. In comparison with the austenitic 316L, the relatively limited number of available surface finishes for Duplex represents a disadvantage of this material.

In order to eliminate this issue, embossing and bright annealing tests are currently being performed on the 2205 at the highly specialized cold rolling facility in Dillenburg.

An easy way to roughly evaluate and compare the corrosion resistance of different stainless steel grades is to consider the pitting resistance equivalent (PRE) value: The higher the PRE value the better the corrosion resistance of the steel. For instance the popular 1.4404 (316L) features a PRE value of approximately 24. If just a moderate increase of corrosion resistance is required, the 1.4435 according to the German DIN (ASTM does not distinguish between 1.4404 and 1.4435 – both are named 316L) with a PRE value of approx. 27 might be an option. Higher corrosion resistance is provided by the 1.4439 (ASTM 317LMN) with a PRE value of 33. The 1.4539 (ASTM 904L with a PRE of 36) is at a very comparable level of corrosion resistance as the Duplex 2205 with a PRE of 35. All these austenitic steel grades (1.4435 (316L), 1.4439 (317LMN) and 1.4539 (904L)) show similar mechanical-technological properties compared to standard 316L (1.4404) and can therefore equally be embossed, polished or tension leveled. Thus, on special request they can all be offered with Outokumpu's wide selection of decorative surface finishes. For an easy comparison the PRE values of the mentioned Duplex and austenitic grades are depicted in one diagram (see Figure 7).

New Developments

In terms of material inquiries, architects are still frequently asking for some sort of a satin or matt finish. Within this context sometimes also omni-directionality is requested which

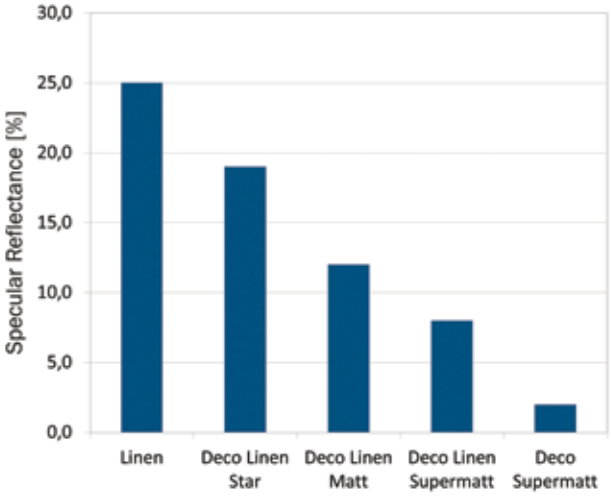

Figure 6. Comparison of specular reflectance for the newly developed Linen versions and Deco Supermatt (Source: Outokumpu)

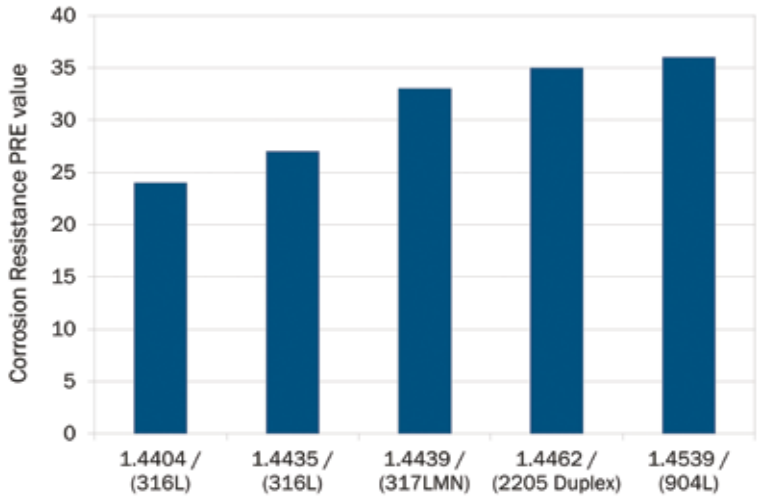

Figure 7. Comparison of the PRE values for highly corrosion-resistant austenitic and Duplex grades (Source: Outokumpu)

automatically leads to the exclusion of any legible pattern-structured finish. The above mentioned Deco Supermatt finish would best fulfill these requirements but due to the solely 2% specular reflectance this surface might be too dull for one or another curtain wall project. Therefore Outokumpu plans to develop such a finish in order to be able to cover this market demand as well. To keep the production costs low, also for this finish every manufacturing process needs to be applied on the coil and never on single sheets.

Conclusion

Stainless steel is an approved and much valued cladding material for sophisticated skyscraper architecture. This paper listed the current façade projects in which Outokumpu acts as the stainless steel supplier. New developments of lively but low reflecting finishes were introduced. This characteristic was achieved by a superposition of a fine and a coarse pattern on one surface. In one development the Haze or the Microlinen pattern serves as the fine - whereas a rolled-on 5WL pattern is the coarse structure. In another development the Linen pattern is the coarse pattern and depending on the applied fine sub-structure, three variously matt-reflecting new surfaces finishes could be engineered. Furthermore, the revised restrictions in Singapore concerning the reflectance of façade material were presented and it was illustrated that three of the newly invented matt finishes are compatible with these strict regulations. The article closes with an outlook on current research activities at Outokumpu to develop a matt and maximal omni-directional surface finish for curtain wall applications.

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