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Authors: Jörn Teipel, Outokumpu
Gert Weiss, Outokumpu

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Stainless-Steel Cladding

不锈钢幕墙

Dr. Jörn Teipel & Gert Weiss, Outokumpu EMEA GmbH (奥托昆普)

Especially during the last 20 years, stainless steel has become an approved and much-valued cladding material for sophisticated architecture. This chapter introduces the embossed stainless steel applied within the façade supplied for PAFC by Outokumpu, and provides an overview of the various façade projects that have been accomplished in the past, giving insight into current activities. Furthermore, the range of potential surface finishes for façade applications is presented. Newspaper articles^{1a, 1b, 2} have recently reported on glare issues that were caused by new buildings in London, Los Angeles, Las Vegas and Hong Kong. These incidents have led to restrictions in Singapore, which are being analyzed and questioned. The consequences that these new regulations have on stainless steel as cladding material are also discussed too. The chapter concludes with a look at current research activities at Outokumpu, which aim to develop duller surface finishes on patterned stainless steel for façade applications.

不锈钢作为复杂建筑构造的外包覆层材料正日益得到认可，且备受重视，这一趋势在近 20 年来尤为明显。本文特别以正在建造的平安金融大厦项目为例，介绍了奥托昆普提供的花纹不锈钢在此项目外立面上的应用及技术。从不锈钢的首例建筑应用（克莱斯勒大厦）入手，本文概要介绍了奥托昆普此前已经完成的各项外立面工程，深入分析其当前活动，同时还介绍了高层建筑外立面应用中的各种表层饰面。很多报纸文章^{1a, 1b, 2}最近报道了伦敦、洛杉矶、拉斯维加斯和香港新楼宇引起的眩光问题。这些事件导致新加坡采取相应限制措施，本文对此做法进行了分析和质询。本文讨论了这些新法规将对不锈钢外包覆层材料造成哪些影响。在最后的结论部分，我们介绍了奥托昆普当前的一些研究活动，希望针对外立面应用开发出花纹不锈钢的无光泽表层饰面。

PAFC Cladding Project

The requirements of the cladding at PAFC were that it be aesthetic, long-lasting, and environment-friendly. After a long bidding process, Outokumpu material was chosen for the cladding. Upon completion, the building will be adorned by the largest stainless steel façade in the world to date, with a total of 1,700 tons of 316L stainless steel material.

As the material supplier, Outokumpu committed to meet the following requirements from the outset of this project:

1. Minimize color difference in large areas using stainless steel through strict process controlling in production.
2. Create the feeling of "low-profile luxury" by using specially designed "Linen" pattern.
3. Preserve the appearance of PAFC more than 100 years in the salty coastal atmospheric conditions of Shenzhen by using the highly corrosion-resistant and high-performance 316L Aluminum
4. Minimize light pollution from the building and be environmentally friendly by using specially designed patterns with controlled refractive indexes
5. Keep the façade clean and reduce maintenance requests and costs by using material that can be easily cleaned by rain.
6. Stick to the project schedule and provide detailed production plan to ensure on-time delivery.
7. Provide solutions and be available for consultancy and guidance throughout the whole process, from materials section to fabrication to implementation and service.

平安金融中心幕墙项目

平安金融中心对外立面选用的材料提出了非常高的要求，主要体现在：美观，外观的持久性，对环境的友好及后期的维护保养方面。经过长期的竞标，奥托昆普的材料最终被选为幕墙材料。摩天大楼落成后，将会是迄今为止，全世界最大的不锈钢外立面。共计将使用约1700吨316L不锈钢。

奥托昆普作为材料供应商，致力于满足项目的要求：

1. 通过精湛的生产过程工艺控制，使大面积不锈钢的色差问题降至最小；
2. 特别设计的不锈钢布纹面传递给人高贵而低调的视觉效果；
3. 具有高耐腐蚀性能的316L不锈钢可以使平安大厦在深圳的海洋空气中，保持幕墙外观一百年不发生变化；
4. 特别设计的花纹及反光效果，最大程度地减少幕墙的光污染，保持对环境的友好；
5. 雨水的冲刷即可保持不锈钢外立面的清洁，最大程度上减少了后期的维护和保养工作及相应费用。

^{1a} <http://www.theguardian.com/artanddesign/shortcuts/2013/sep/03/walkie-talkie-death-ray-buildings-heat>

^{1b} <http://www.bloomberg.com/news/2013-09-05/london-s-walkie-talkie-fryscraper-draws-crowds-in-heat.html>

² www.info.gov.hk/gia/general/201301/23/P201301230412.htm



Figure 4.17. Rendering of the building's stainless-steel façade. (Source: KPF)

图4.17 平安金融中心不锈钢立面效果图 (来源: KPF)

Stainless Steel in Architecture: Background

Shortly after its invention in the early 20th century, stainless steel was discovered by architects as a cladding material. The first impressive example of stainless steel for high-rise architecture is on the 56-meter-high spire of the 319-meter-tall Chrysler Building in New York City in 1930. The German company Friedrich Krupp AG in 1911 licensed some V2A austenitic stainless steel (a precursor of today's Grade 304/1.4301) for the use on the Chrysler Building. 80 years after the completion of this art deco masterpiece, the spire sparkles preciously in the New York skyline (see Figure 4.17). Maintenance of the stainless steel spire was only necessary twice, and none of the elements have needed to be replaced yet. On the basis of this building example, one can demonstrate the three qualities that characterize stainless steel: durability, functionality and beauty. If architects are asked why they are using stainless steel in visual architectural applications, they commonly refer to the "honesty" and "pureness" of the material. Its main draw remains its sparkle and durability.

6. 紧贴项目进度，提供详细的供应方案，确保项目如期完成；
7. 从选材到后期材料加工，奥托昆普提供完善的技术咨询及解决方案。确保幕墙公司和加工商在加工和安装过程中正确使用及保护不锈钢。

不锈钢在建筑领域的应用: 背景综述

不锈钢发明于 20 世纪早期，建筑师很快便发现它适合作外覆层材料。直至今日，不锈钢在高层建筑上的首次应用依然令人印象极其深刻：即位于纽约市，建于 1930 年，高达 319 米的克莱斯勒大厦上 56 米高的巨型尖顶。德国弗里德里希·克虏伯股份公司 (German Friedrich Krupp AG) 于 1911 年发明了 V2A 级奥氏体不锈钢 (当今所称 304/1.4301 的前身)，首次授权在克莱斯勒大厦上使用。在这一艺术装饰杰作完工 80 多年后，其尖顶仍在纽约上空熠熠生辉 (见图 4.17)。仅针对不锈钢尖顶进行过两次必要的保养，尚无任何元件需要更换。该建筑案例深刻展示了不锈钢的三个代表性特征：耐用性、功能性和美观性。如果有人问建筑师，他们为什么要在视觉建筑应用中使用不锈钢，得到的答案通常是这种材料“可靠”、“纯粹”。其主要吸引人的特点还是反光及耐用。

我们相信，再过几十年甚至几百年，平安国际金融中心依然以其时尚、光洁、美观的外观俯视深圳的美丽夜景。

此外，当前绿色建筑的趋势也有利于不锈钢的发展。2013 年，奥托昆普不锈钢产品的回收原料使用率超过了 85%。100% 可回收加上低维护要求，这种可持续建筑应用的绿色材料具有碳足迹整体较低的鲜明特点。

通过使用奥托昆普的不锈钢材料，平安金融中心进一步降低了碳排放，“以可持续的实例彰显深圳的开创精神”。

与此项目相隔时间不远的案例包括：1991 年，奥托昆普采用高抗腐蚀含钼 316L，为美国加州科斯塔梅萨的广场大厦 (Plaza Tower) 生产了约 200 吨的亚麻花纹材料。所交付的板材厚度为 1.8 毫米，宽度为 1500 毫米，包含各种长度。广为人知的另一杰作是世界知名的摩天大楼吉隆坡双子塔。双子塔竣工于 1999 年，高 450 米，奥托昆普为其提供了 83,500 平方米的不锈钢覆层。就在同一时期，奥托昆普负责为德国杜塞尔多夫 (Düsseldorf)³ 的 Neuer Zollhof 大楼制造了经退火处理的光亮材料，这栋大楼的设计师是

We believe that after decades or even hundreds of years, PAFC will still be a primary example of stainless steel's resiliency and durability; shining beautifully in the night sky of Shenzhen.

Moreover, stainless steel is beneficial for the current green building trend. In 2013, stainless steel products by Outokumpu had an average recycling content of over 85%. Its 100% recyclability, together with its low maintenance and consequently small carbon footprint, give stainless steel to play an integral role in the green building industry.

By using stainless steel, PAFC further reduces its carbon footprint and reflects its dedication to providing a sustainable testament to the pioneering spirit of Shenzhen.

Recent reference buildings for this project include the following. In 1991, Outokumpu produced approximately 200 metric tons of Linen-patterned material in highly corrosion resistant molybdenum containing Grade 316L for the Plaza Tower in Costa Mesa, California, USA. The delivered sheets had a thickness of 1.8 mm, a width of 1500 mm and diverse lengths. Another skyscraper utilizing an 83,500 m² stainless steel cladding was the 450-meter-tall Petronas Twin Towers in Kuala Lumpur, which were completed in 1999. In the same period, Outokumpu produced the bright annealed material for the "Neuer Zollhof" in Düsseldorf, Germany³ which, was designed by Frank O. Gehry. In 2010, another key reference building with a stainless steel cladding was completed – the Burj Khalifa in Dubai, UAE.

The bright accentuated edges on the One World Trade Center in New York City, USA were another key reference project. In total, 175 metric tons of patterned material of Grade 316L were produced between 2008 and 2009 for this building. The architects of Skidmore, Owings & Merrill LLP (SOM)⁴ requested a surface finish with a random structure, and brighter than the well-established "Linen" pattern. The new pattern, called "Laser," was specifically developed for this application to comply with the architect's requirements. "Laser" consists of digitized micro-patterns which are irregularly arranged, i.e. without pattern repetition (see Figure 4.18). This results in a stainless steel surface with a genuine random structure. Under all viewing angles and light conditions, a homogeneous surface is observed. For comparison, Figure 5 also shows the standard Linen pattern, with its regularly arranged alternating large and small ovals. Gloss and brightness vary according to the viewing angle. Therefore, the process flow direction during embossing needs to be considered when placing the façade elements onto the building.

Current façade projects include the new UBS Headquarters (5 Broadgate) in London, UK. The architects wanted to give the building the appearance of a large motor block⁵. This idea is implemented by covering the building with either glass or up to 6-meter-long Linen-patterned stainless steel sheets of Grade 316L. The fraction of stainless steel that is utilized for covering this building is extraordinarily high, and this material will hopefully serve as a role model for the cladding of future building projects in the neighborhood.

For the Ilham Baru (IB) Tower in Kuala Lumpur, Malaysia, designed by Foster + Partners⁶, Alcoa Architectural Products produced stainless steel composite panels for the façade. The product is called Reynobond and consists of a 0.4-mm outer sheet in 316L with Linen pattern, a core of 3-mm plastic material and a 0.4-mm inner sheet in 316L with standard bright annealed surface. The composite has the advantage of being light and stiff, making it very efficient.

One Bryant Park⁷, placed in a prime location of New York City, USA and designed by Pei Cobb Freed & Partners, focuses on a sharp-edged optical effect derived from of Linen-patterned 316L façade elements.

Frank O. Gehry. 完成不锈钢的这一重要代表性工程后，奥托昆普在新世纪的外立面应用中，不锈钢的订单数量显著增加。2010年，又一座采用奥托昆普不锈钢覆层的重要代表建筑竣工：位于阿联酋迪拜的迪拜塔。

美国纽约市拥有明亮突出边缘的新世贸中心一号楼是奥托昆普的另一项重要代表工程。从2008年到2009年，我们共为新世贸中心一号楼提供了175吨316L花纹材料。Skidmore, Owings & Merrill LLP (SOM)⁴的建筑师要求采用具有随机结构，且较为接受的“亚麻”花纹更为光亮的表层饰面。为满足建筑师的要求，我们为此应用专门开发出新的花纹，称为“激光”。“激光”是首款具有真正随机结构的不锈钢表层，不会出现重复花纹（见图4.18）。在所有观看角度和光线条件下，都可以观察到均匀的表层。为了比较，图5也展示了具有规则和大小凹凸纹路的普通“亚麻”花纹。光泽和亮度与观察角度有关，因而在建筑外立面幕墙安装时需要考虑花纹的方向。

现有外立面工程还包括位于英国伦敦的新瑞银集团总部（布罗德盖特5号）。建筑师希望让整栋建筑看上去像一个大型发动机块⁵。为了实现这个想法，他们采用玻璃以及长达6米的316L亚麻花纹不锈钢板材外包装建筑表面。用于此建筑物的不锈钢比例非常高，这种材料将有望成为周边未来建筑工程的外墙典范。

位于马来西亚吉隆坡的伊巴鲁塔 (IB) 由 Foster + Partners⁶ 设计。Alcoa Architectural Products 公司针对该外立面项目生产出 不锈钢复合板材。该产品称为铝塑复合板 (Reynobond)，外板材是 0.4 毫米的 316L 亚麻花纹，核心为 3 毫米的塑性材料，内板材是 0.4 毫米具有标准光亮退火表层的 316L 材料。这种复合材料既轻便又坚固，使用起来非常高效。

布莱恩公园 1 号⁷ 建筑位于美国纽约市的黄金地段，由 Pei Cobb Freed & Partners 设计，重点突出亚麻花纹 316L 外立面元素的锋利光芒。

新的亚马逊总部位于美国西雅图，由 nbbj⁸ 设计，我们为其提供因抛丸处理而显出无光泽的表层（称为“超哑光”）和 2B（退火和酸洗）表层。“超哑光”表层饰面常

³ http://en.wikipedia.org/wiki/Neuer_Zollhof

⁴ www.som.com/projects/one_world_trade_center

⁵ www.makearchitects.com/projects/5-broadgate

⁶ www.fosterandpartners.com/projects/ilham-baru

⁷ <http://7bryantpark.com>

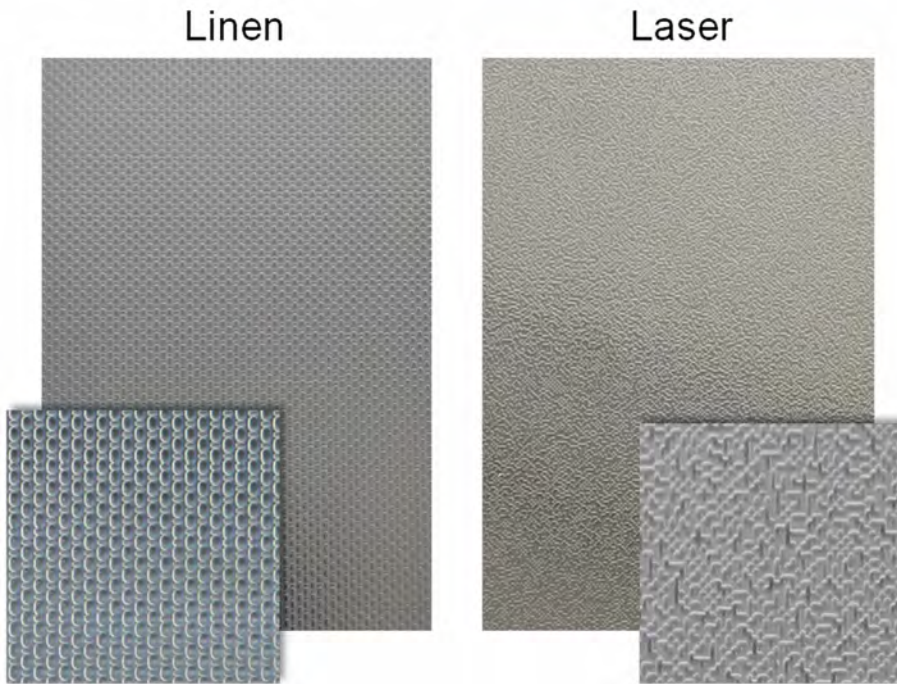


Figure 4.18. Visual comparison of Linen versus Laser pattern (Source: Outokumpu)
图4.18. 亚麻表层与激光表层的视觉对比 (来源: 奥托昆普)

For the new Amazon Headquarters in Seattle, USA, designed by NBBJ⁸, a shot-blasted, dull surface (called “supermatt”), together with a 2B (annealed and pickled) surface was delivered. The “supermatt” surface finish is commonly used for roofing applications and was here introduced on a façade, for the first time. Additionally, both surface finishes are electrolytically colored in red, green “champagne” and are placed with different widths and lengths, vertically and horizontally on the façade.

The Delivery Range of Different Grades and Surfaces for Architectural Applications

Façade material must meet the highest quality standards. Consequently, special effort is vital when this material passes through the production process. Particular attention is drawn to the visual appearance because the façade needs to be as homogeneous as possible, requiring constant oversight of production parameters. Equally important is the flatness of the product. In order to achieve an overall uniform, accurate and even appearance of the cladding, all the façade elements need to have an exquisite flatness, obtained by tension leveling. The tension leveling process serves two purposes. Firstly, residual stresses are equalized. Secondly, the strip becomes completely flat. The stainless steel experiences a hardening effect during embossing, therefore, a final recovery annealing needs to be performed on the strip in order to ensure appropriate formability.

Another group of finishes is represented by polished surfaces. The polishing technique (dry, wet, duplo or microlon), together with the selected grit size influences, surface roughness and gloss and therefore strongly determines the final visual appearance of the material.

Another surface, 2R², has a particularly high gloss that can be as high as 60% at a 20° angle. The surface is not mirror polished and achieves its high gloss only by process steps directly applied to the coil on the regular mill facilities. On the other side of the gloss spectrum the dull finish “supermatt” is a shot-blasted surface and has a gloss of just 0.2% at 20° and 1.5% at 60° angle. A “Deco Matt’s” decorative rough surface is achieved by a combination of deco rolling, pickling and brushing.

Concerning the selection of grades for façade applications, in the vast majority of cases Grade 316L is utilized, as it features both good formability and weldability. It contains approximately 17% chromium, 2% molybdenum and 10% nickel. The addition of molybdenum makes it more resistant in marine aerosol containing environments compared to the standard Grade 304. Nevertheless, a cleaning interval of once to twice a year is recommended for 316L depending

见于屋顶应用，本案是其首次应用于外立面。另外，两种表层饰面通过电解方式着色为红色、绿色和香槟色，采用不同的宽度和长度，置于外立面的垂直方向和水平方向上。

不同建筑应用表面的钢种和产品

覆层材料必须满足最高的质量标准，因此需要在生产过程中给予额外关注。外观尤其需被重视，即使不同的生产批次也要通过保持恒定的生产参数。材料的平面度也同样重要。为了保证幕墙表面的整体统一和均匀，所有的覆层材料都需要具有完美的平面度。拉伸矫直可以实现两个目的：第一使残余应力平衡，第二使钢带完全平整。由于不锈钢在压花过程中会发生硬化效应，所以需要 对钢带进行退火处理加以恢复，以确保良好的成型性能。

另一组饰面由抛光表层来表示。抛光技术（干式、湿式、双工或美光）和所选粒度会影响表面粗糙度和光泽度，进而在很大程度上决定了材料的最终外观。

奥托昆普还可提供称为“2R²”的表面，具有特别高的光泽度（20°角时最高可达 60%）。该表面不是镜面抛光，其高光泽度的实现完全是通过直接应用在常规轧机设备上生产带钢的工艺步骤。在光泽度频谱的另一端，奥托昆普可生产前文所述的无光泽饰面，称为“超哑光”。这种表面经过抛丸处理，在 20°角时光泽度仅为 0.2%，60°角时为 1.5%。这种近似无光泽的饰面显示了奥托昆普的“装饰哑光”能力。它表面粗糙，装饰性极强，通过组合运用装饰轧制、酸洗和刷磨来实现此效果。

在牌号的选择上，316L 是最为普遍的一种牌号。316L 同时具有很好的成型性和焊接性。316L 含有 17% 的铬、2% 的钼，以及 10% 的镍。其中的钼使得 316L 比 304 具有更好的抵御海洋气候环境的能力。对于 316L，我们建议可以根据距海边的距离、雨水量、空气湿度以及污染物总量，每年进行一到两次的清洗。目前世界上有一个地区，其腐蚀程度之高，连 316L 都不能适应外立面应用。这个地方就是波斯湾地区。几种腐蚀条件的共同存在造成

⁸ <http://www.nbbj.com/work/amazon>

on the proximity to the sea, amount of rain, air humidity and contamination with air pollutants. There is one particular region in the world where the corrosion load is so high that even Grade 316L is no longer recommended for outside applications: the bordering territory around the Persian Gulf. Several corrosion-inducing factors come together here, generating this severe environment. First is the the lack of rain. It leads to a fast accumulation of dust, sand and salt, which form an adherent deposit on the stainless-steel surface. This deposit contains small crevices, in which condensed humidity can act as an electrolyte to induce corrosion. The high temperatures during daytime even accelerate the corrosion process. In these harsh conditions the author recommends the utilization of the Duplex Grade 2205 (1.4462) for outside applications. The 2205 contains approximately 22% chromium, 3% molybdenum and 6% nickel.

Statutory Regulations on the Reflectivity of Façades

To protect neighboring buildings and their residents from glare due to direct sunlight reflection, cities such as Sydney and Singapore have imposed regulations to limit the “daylight reflectance” of façades to a total of 20%^{9,10,11}. In this content, the term “daylight reflectance” refers to the sum of both the specular and diffuse reflection of the façade material. The drive to regulate the reflectance of buildings intensified after the rumors spread that the reflected sunlight beam of the London skyscraper nicknamed “Walkie Talkie” had melted parts of a vehicle^{1a}. Due to the concave shape of the southern glass façade of this building, the reflected sunlight was virtually concentrated into a beam aimed at the street opposite the building. In a

⁹http://www.bca.gov.sg/BuildingControlAct/others/Building_Control_Regulations.pdf

¹⁰<http://www.corenet.gov.sg/einfo/Uploads/Circular/CBCA131028.pdf>

¹¹http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0020/128018/4_WEB_Section3_DCP2012_130213.pdf



Figure 4.19. The stainless-steel façade being installed on the building. (Source: Ping An)
图4.19. 平安金融中心已安装不锈钢立面 (来源: 平安)

了这种严苛的环境。首先，由于缺乏降雨，不锈钢表面很快就聚集了大量的盐和沙尘。在沙尘缝隙中浓缩的水汽作为电解质而引发腐蚀。而白天的高温环境，则加剧了腐蚀的过程。在这种严苛的环境下，奥托昆普会建议外立面使用双相不锈钢等级牌号2205 (1.4462)。2205含有22%的铬、3%的钼和6%的镍。

有关外立面反射率的法律规定

为保护邻近建筑物及其中的居民避免受到阳光直射造成的眩光，悉尼、新加坡等城市已经实施监管，将外立面的“日光反射率”限定为总计不超过 20%^{9,10,11}。此处提到的术语“日光反射率”是指外立面材料的镜面反射和漫反射之和。英国伦敦有一栋俗称“对讲机”的摩天大楼，它的反射阳光束竟然将车辆零件融化了！在这则谣言流传开来之后，推动监管建筑物的反射率一下成为现实^{1a}。这栋楼的南面玻璃外立面呈凹形，所反射的太阳光几乎都聚焦到光线指向的对面街道和人行道上。在新加坡国家发展部的一则公告中，提到了伦敦的这一事件和香港高层建筑的眩光问题（环球贸易广场 ICC），并将其作为更新反射率法规的引发契机¹²。然而，这个 20%“日光反射率”限制的后果是，使合适覆层材料的选择变得十分有限。如果依据此规定，无论制造材料是不锈钢还是铝，任何一种无涂层的金属覆层都无法满足要求。将表层涂成黑色或许是走出此困境的一个方法，但这不是一个合适的解决方案，尤其是对于不锈钢，因为这会破坏材料的主要视觉特性。

减少金属表层镜面反射率的常用方法是增加其粗糙度。通过应用这种技术，上述“超哑光”表层在 20°角时的镜面反射率仅为 0.2%。另一方面，粗糙会导致漫反射显著增加。因

posting by the Ministry of National Development of Singapore this incident in London, together with the glare problem of the tallest building in Hong Kong (International Commerce Centre, ICC), was mentioned as a trigger for updating the reflectivity regulations¹². However this restriction to 20% “daylight reflectance” does have a bearing on the selection of suitable cladding material for a tall building. No uncoated metal cladding (regardless of whether it consists of stainless steel or aluminum) fulfills this regulation anymore. Painting the surface black could be a loophole out of this dilemma, but especially for stainless steel, this would not be an appropriate solution, as this would destroy the material’s characteristics.

A common method for reducing the specular reflection of a metallic surface is to increase its roughness. By applying this technique, the above-mentioned supermatt surface has a specular reflectance at 20° angle of just 0.2%. On the other hand, roughening leads to a dramatic increase of diffuse reflection. Therefore, no matter which roughness/gloss level is applied to the façade material, the sum of specular and diffuse reflection (“daylight reflectance”) will remain approximately constant.

In conclusion, it is problematic for metallic sheets that the “daylight reflectance” does also include the diffuse reflection. Unfortunately the result of this regulation is that due to physical limitations, uncoated metallic sheet material can never fulfill the required 20% “daylight reflectance” requirement and therefore can no longer come into consideration for façade applications in jurisdictions with this requirement.

It is also worth mentioning that the two glare problems to which the posting of the Ministry of National Development refers were in both cases provoked by glass and additionally by the concave shaping of the façade. The same applies to the crescent-shaped Vdara Hotel and Spa in Las Vegas, with its large glass front^{1b}. The newspaper article^{1b} also mentions glare problems caused by stainless-steel panels Frank O. Gehry’s Walt Disney Concert Hall in downtown Los Angeles. Once again, in this example the small percentage of glaring cladding area was concave or crescent-shaped, and the initial surface finish was burnished. The glare problems were solved after sanding down the metal surface, which led to a duller appearance.

Furthermore, as the above-mentioned exemplary cases impressively demonstrate, it is the specular reflection that predominantly causes these glare problems. Hence the main focus for regulations should always be put on the specular reflection. Luckily it seems that the Building and Construction Authority in Singapore has an open ear for industry concerns and a case by case approach was indicated, together with an accommodating statement concerning the maximum acceptable percentage value for the specular reflection.

Conclusion: New Developments

Due to the concession of the Singapore authorities, Outokumpu started the development of new duller surface finishes with a lower specular reflection. As commonly patterned surfaces are used for façade applications the focus will also be on 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 development is to maintain the initially mentioned liveliness and sparkle that characterizes stainless steel, but simply to apply it in a damped down, overall duller-appearing sheet.

此，无论调整外立面材料的何种粗糙度/光泽度，镜面反射和漫反射之和（等于“日光反射率”）将大体上保持不变。

总之，金属板材的问题在于，“日光反射率”还包括漫反射。不幸的是，这项监管规定导致由于物理限制，无涂层的金属板材材料绝对无法满足所要求的 20% “日光反射率”，因而在外立面应用中再也不能考虑使用它。

同样值得一提的是，新加坡国家发展部公告中提到的这两个眩光问题都是由于玻璃和外立面的凹形共同导致的。这种情况同样适用于拉斯维加斯的月牙形 Vdara Hotel and Spa 酒店以及它的大片玻璃前立面^{1b}。在同一篇报纸文章^{1b}中还提到，洛杉矶市中心 Frank O. Gehry 的沃尔特·迪斯尼音乐厅采用的不锈钢板材也会导致眩光问题。在这个例子中，小比例眩光覆盖区域同样是凹形或月牙形，原有的表层饰面为抛光。将金属表面进行打磨之后，解决了眩光问题，但同时也导致了建筑外观的平淡乏味。

此外，从上述极端情形不难看出，这些眩光问题主要是由镜面反射造成。因此，法规的重点应始终放在镜面反射问题上。非常幸运，新加坡建设局开明地听取了奥托昆普的意见，表示将采取个案决定方式，并就镜面反射可接受的最大百分比发表了声明。

结论：幕墙领域的新发展

鉴于新加坡当局所作的让步，奥托昆普开始开发新的无光泽表层饰面，实现较低镜面反射率。由于常用花纹表层用于外立面应用，因此重点也将是开发这种类型的饰面。无光泽表层的早期发展表明，那些饰面容易会显得有点“死气沉沉”。因此，这次开发工作的挑战在于，在维持不锈钢与生俱来的上述活泼与闪耀感的同时稍加抑制，使板材外观整体上减少光泽。

¹² <http://mndsingapore.wordpress.com/2013/10/24/be-considerate-to-the-neighbourhood>