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Stainless Steel Claddings for High-Rise Architecture

高层建筑不锈钢幕墙

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Jörn 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. In 2006 he began his professional career at a technical consultancy in Frankfurt am Main. In 2009 he joined ThyssenKrupp Steel where he was responsible for the business development for magnesium flat products. In 2011 he transferred to ThyssenKrupp Nirosta in Krefeld – now Outokumpu where he is in charge of the technical customer service for all architectural applications.

Joern Teipel先生先后在德国波恩和美国哥伦布市的俄亥俄州立大学攻读物理学，并于 2006 年获得非线性光学专业的博士学位。2006 年，他加入位于美因河畔法兰克福的一家技术顾问公司，开始了自己的职业生涯。2009 年，他加入蒂森克虏伯钢铁公司 (ThyssenKrupp Steel)，负责镁合金板材产品的业务开发工作。2011 年，他调岗至位于克雷菲尔德的蒂森克虏伯尼罗斯塔公司 (ThyssenKrupp Nirosta)，即现在的奥托昆普，负责所有建筑应用领域的技术客户服务工作。

Gert Weiss studied metallurgy in Duisburg, Germany. Between 1988 and 2000 he worked as an engineer in the production of ThyssenKrupp Nirosta. Already during this time he was deeply involved in various façade projects. In 2000 he transferred to the technical customer service of ThyssenKrupp Nirosta that he is heading since then. Many important façade projects like One World Trade Center have been supported by his department. After the merger with Outokumpu in 2013 he is now head of technical customer service of the European factories in Finland and Germany.

Gert Weiss 先生曾在德国杜伊斯堡攻读冶金学。1988 年至 2000 年，他在蒂森克虏伯尼罗斯塔公司的生产部门担任工程师。在此期间，他已经深入参与各项外立面工程。2000 年，他调岗至蒂森克虏伯尼罗斯塔公司的技术客户服务部门，此后一直担任领导职务。其所在部门为众多重要外立面工程提供支持，其中包括新世贸中心一号楼。2013 年，公司与奥托昆普合并，此后他一直在欧洲工厂设于芬兰和德国的技术客户服务部担任领导职务。

Abstract

Especially during the last 20 years stainless steel has become an approved and much valued cladding material for sophisticated architecture. Starting with the first architectural application of stainless steel (the Chrysler Building) this article provides an overview of the various façade projects that have been accomplished in the past and gives insight in the current activities. Furthermore the delivery range of 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 discussed. The article concludes with a look on current research activities at Outokumpu which aim to develop duller surface finishes on patterned stainless steel for façade applications.

Keywords: Stainless Steel, Façade, Cladding, Curtain Wall, Surface, Reflectance

摘要

建筑面材不锈钢已批准成为复杂建筑构造的面材，备受重视，这一趋势在近 20 年来尤为明显。本文从不锈钢的首例建筑应用 (克莱斯勒大厦) 入手，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，同时还介绍了奥托昆普针对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，目前正对此做法进行分析和质询。本文讨论了这些新法规会对将不锈钢作为建筑面材造成哪些影响。文末还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。

关键词: 不锈钢、外立面、建筑面材、幕墙、表面、反射率

Stainless Steel in Architecture

Shortly after its invention in the early 20th century stainless steel was discovered by architects as a cladding material. The up to now very impressive example of the first utilization of stainless steel for high-rise architecture is the giant 56 meter high spire of the 319-meter tall Chrysler Building in New York City back in 1930. The German Friedrich Krupp AG licensed its in 1911 invented grade V2A austenitic stainless steel (a precursor of today's known Grade 304/1.4301) for the use on the Chrysler Building. Still more than 80 years after the completion of this art deco masterpiece the spire sparkles preciously in the New York sky (see Figure 1). Maintenance of the stainless steel spire was only necessary

不锈钢在建筑领域的应用

不锈钢发明于 20 世纪早期，建筑师很快便发现它适合用作建筑面材。直至今天，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 1)。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"。对不锈钢的其他描述则强调了其与视觉外观的联系，例如: 活力、光洁、闪耀。而由于这种材料具有高持久性和耐腐蚀性，持久、耐用、永恒等词汇也常有耳闻。

[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

twice and none of the elements needed to be replaced yet. On the basis of this building example one can impressively demonstrate the three qualities that characterize stainless steel: durability, functionality and beauty. If architects were asked why they are using stainless steel in visual architectural applications, commonly the "honesty" and "pureness" of the material is referred to. Other expressions used for stainless steel that stronger relate to the visual appearance are liveliness, sparkle and glittering. Due to the high persistence and resistiveness of the material terms like long-lasting, durable and eternal are often heard as well.

Nowadays especially for outstanding high-quality architecture (e.g. skyscrapers, museums, headquarters or airports) stainless steel is preferably used for claddings or roofs.

Moreover the current Green Building trend is advantageous for stainless steel. In 2013 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 material for sustainable building applications.

Outokumpu has a long legacy in the architectural field and can look back on more than 20 years of experience of providing stainless steel sheets for façade applications for tall buildings. In 1991 Outokumpu produced approx. 200 metric tons of Linen-patterned material in highly corrosion resistant molybdenum containing Grade 316L for the Plaza Tower in Costa Mesa, California (USA) (see Figure 2). The delivered sheets had a thickness of 1.8 mm, a width of 1500 mm and diverse lengths. The building was designed by Pelli Clarke Pelli Architects[3] who are also known for another world famous skyscraper with an 83.500 m^2 stainless steel cladding supplied by Outokumpu – 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, Germany[4] which was designed by Frank O. Gehry (see Figure 3). After the completion of this key reference project for stainless steel the numbers of orders for façade applications increased significantly in the new century.

In 2010 another key reference building with a stainless steel cladding by Outokumpu was completed – the Burj Khalifa in Dubai, UAE. The publicity caused by this project together with the fact of the overcoming of the world financial crisis boosted once again significantly the number of façade activities.

The bright accentuated edges on the One World Trade Center in New York City, USA were another key reference project for Outokumpu (see Figure 4). 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)[5] 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 architects requirements. "Laser" consists of digitalized micro-patterns which are irregularly arranged, i.e. without pattern repetition (see Figure 5). 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

Figure 1. Sparkling spire of the Chrysler Building (Source: Outokumpu)
图1. 克莱斯勒大厦，尖顶熠熠生辉 (来源: 奥托昆普)

Figure 2. Plaza Tower in Costa Mesa, CA (USA). Even more than 20 years after its completion the façade has not lost any of its original beauty. (Source: Pelli Clarke Pelli Architects)
图2. 美国加州科斯塔梅萨的广场大厦，竣工20多年后，外立面仍不失当年风采 (来源: Pelli Clarke Pelli Architects)

Figure 3. Neuer Zollhof in Düsseldorf, Germany (Source: Outokumpu)
图3. 德国杜塞尔多夫的 Neuer Zollhof大楼 (来源: 奥托昆普)

[3] http://pcparch.com/project/plaza-tower
[4] http://en.wikipedia.org/wiki/Neuer_Zollhof
[5] www.som.com/projects/one_world_trade_center

Figure 4. One World Trade Center in New York City, NY (USA) (Source: Joe Mabel)
图4. 美国纽约新世贸中心一号楼 (来源: 维基百科)

arranged alternating large and small ovals. Gloss and brightness vary according to the viewing angle and 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. Make Architects have the vision to give the building the appearance of a large motor block [6]. 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 (see Figure 6).

For the Ilham Baru (IB) Tower in Kuala Lumpur, Malaysia which is designed by Foster + Partners[7] the company Alcoa Architectural Products produces 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 which makes it very efficient.

The building 7 Bryant Park[8] placed in a prime location of New York City, USA and designed by Pei Cobb Freed & Partners focuses on a sharp-edged optic of Linen-patterned 316L façade elements.

For the new Amazon Headquarters in Seattle, USA designed by nbbj[9] a shot blasted and therefore very dull surface (called "supermatt")

[6] www.makearchitects.com/projects/5-broadgate
[7] www.fosterandpartners.com/projects/ilham-baru
[8] http://7bryantpark.com
[9] http://www.nbbj.com/work/amazon

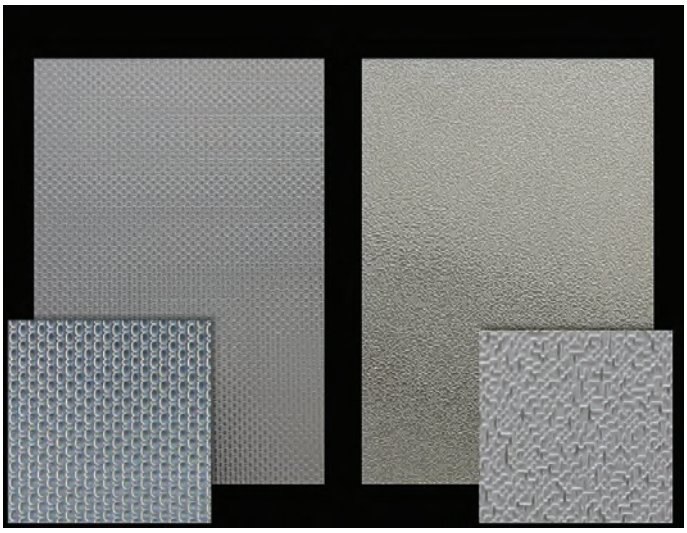

Figure 5. Visual comparison of Linen versus Laser pattern (Source: Outokumpu)
图5. 亚麻表层与激光表层的视觉对比 (来源: 奥托昆普)

如今，不锈钢已成为建筑面层或屋顶的理想材料，对于摩天大楼、博物馆、总部或机场等杰出的高品质建筑来说尤其如此。

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，因此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。

奥托昆普在建筑领域耕耘已久，丰富经验可以追溯到 20 多年以前，为众多高层建筑提供外立面用的不锈钢板材。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 (见图 2) 。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。负责大厦设计的建筑事务所是 Pelli Clarke Pelli Architects[3]，其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 平方米的不锈钢建筑面材。就在同一时期，奥托昆普负责为德国杜塞尔多夫 (Düsseldorf) [4]的 Neuer Zollhof大楼制造光亮退火材料，这栋大楼的设计师是 Frank O. Gehry (见图 3) 。完成不锈钢的这一重要参考工程后，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建筑面材的重要参考建筑竣工: 位于阿联酋迪拜的迪拜塔。该项目的知名度蜚声国际，又恰逢成功应对世界金融危机，因而再次显著提升了奥托昆普的外立面项目活动数量。

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参考工程 (见图4) 。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) [5]的建筑师要求采用具有随机结构，较之广为接受的"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5) 。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，因而在往建筑上安装外立面幕墙时就要在其生产过程中就需考虑花纹的方向。

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电机座[6]。为了

together with a 2B (annealed and pickled) surface was delivered. The "supermatt" surface finish is commonly used for roofing applications and is in this case for the first time introduced on a façade. Additionally both surface finishes are electrolytically colored in red, green and champagne and are placed with different widths and lengths, vertically and horizontally on the façade.

Another current and so far largest façade project for Outokumpu is the Ping'An Financial Center in Shenzhen, China[10]. Approximately 1700 metric tons of Linen-patterned 316L are produced in 2013 and 2014. For Outokumpu this is a huge honor to supply the sheets for the façade of China's highest skyscraper after its completion (see Figure 7). Architect of Ping'An is Kohn Pedersen Fox.

The Delivery Range of Different Grades and Surfaces for Architectural Applications

Façade material must meet the highest quality standards and therefore special effort is necessary when this material passes through the production process. Particular attention is drawn to the visual appearance as this needs to be as homogeneous as possible, also among different production batches. This homogeneity is achieved by keeping production parameters as constant as possible. Equally important is flatness. In order to achieve an overall uniform, accurate and even appearance of the cladding all the façade elements need to have a perfect flatness. Such flatness is obtained by tension leveling which is compulsory for façade material at Outokumpu. Tension leveling serves two purposes: first, residual stresses are equalized and second, the strip becomes completely flat. As the stainless steel experiences a hardening effect during embossing, a final recovery annealing needs to be performed on the strip in order to ensure good formability.

The above presented activities already indicate that Linen pattern is the most common surface finish for façade projects at Outokumpu. The reason why Linen is so often favored by architects is the extraordinary texture that this pattern offers. Even though the eye can no longer resolve the actual pattern from a certain distance on the material appears more uniform, consistent and classy compared to non-patterned material. Light is reflected more diffuse rather than directional resulting in a more matt look. A small portion of the light although is specularly reflected from the Linen pattern elements leading to an appealing glittering effect.

Of course there exists a much larger range of surfaces for cladding applications than just Linen. Besides standard 2B (annealed and pickled) and BA (bright annealed) finishes Outokumpu offers more than 25 surface patterns. The most popular ones are Linen, Square, Diamonds, Leather Grain, Austenite, Microlinen and Haze. Also completely new, customized patterns can be embossed on stainless steel in the mills.

Another group of finishes is represented by the 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.

Outokumpu also offers surfaces called 2R[2] with a particularly high gloss (up to 60% at 20°angle). The surface is not mirror polished and achieves its high gloss only by process steps directly applied to the coil

[10] http://www.kpf.com/project.asp?ID=163

Figure 6. 5 Broadgate in London, United Kingdom (Source: Make Architects)
图6. 英国伦敦的新瑞银集团总部 (布罗德盖特 5 号) (来源: make architects)

Figure 7. Ping'An Finance Center in Shenzhen, China (Source: Kohn Pedersen Fox)
图7. 中国深圳平安金融中心 (来源: Kohn Pedersen Fox)

实现这个想法，他们在建筑物上覆盖玻璃或者长达 6 米的 316L 亚麻花纹不锈钢板材。用于覆盖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建筑面材典范 (见图 6) 。

位于马来西亚吉隆坡的伊巴鲁塔 (IB) 由 Foster + Partners[7] 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。该产品称为不锈钢复合板 (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 7 号[8]建筑位于美国纽约市的黄金地段，由 Pei Cobb Freed & Partners 设计，重点突显出亚麻花纹 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 nbbj [9]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。

奥托昆普另一个现有也是迄今最大的外立面工程是位于中国深圳的平安金融中心[10]，在2013 和 2014 年中，我们将为此项目提供约 1700 吨亚麻花纹的 316L 材料。对于奥托昆普而言，能够在中国最高的摩天大楼落成后，为其提供外立面板材是一项至高荣誉 (见图 7) 。设计平安大楼的建筑事务所是 Kohn Pedersen Fox。

on the regular mill facilities. On the other side of the gloss spectrum Outokumpu produces the earlier mentioned dull finish called "supermatt". It is a shot blasted surface and has a gloss of just 0.2% at 20° and 1.5% at 60° angle. A similar dullness shows Outokumpu's "Deco Matt" finish. Its highly 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. 316L 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 aerosols containing environments compared to the standard Grade 304. Nevertheless, also with 316L a cleaning interval of once to twice a year is recommended depending 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 extremely 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 of all the lack of rain 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 Outokumpu recommends the utilization of the Duplex Grade 2205 (1.4462) for outside applications. The 2205 contains approximately 22% chromium, 3% molybdenum and 6% nickel.

A dedicated team at Outokumpu is specialized on guiding architects and builders concerning the selection of stainless steel grades and surfaces. Even customized finishes upon special request for exterior or interior claddings can be developed.

Statutory Regulations on the Reflectivity of Façades

To protect neighboring buildings and its residents from glare due to direct sunlight reflection cities like Sydney and Singapore have imposed regulation to limit the "daylight reflectance" of façades to a total of 20%[11,12,13]. 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 became very present 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 focused to a sunbeam pointing down to the opposing street and sidewalk. In a 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 trigger to update the reflectivity regulations[14]. However this restriction to 20% "daylight reflectance" does have the consequence that the selection of suitable cladding material will become rather limited. No

[11] http://www.bca.gov.sg/BuildingControlAct/others/Building_Control_Regulations.pdf
[12] http://www.corenet.gov.sg/einfo/Uploads/Circular/CBCA131028.pdf
[13] http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0020/128018/4_WEB_Section3_DCP2012_130213.pdf
[14] http://mndsingapore.wordpress.com/2013/10/24/be-considerate-to-the-neighbourhood

不同建筑用钢种和表面的供货范围

建筑面材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来尽可能的实现材料表层均匀。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，所有的建筑面材都需要具有完美的平面度。所有奥托昆普建筑面材都必须通过拉伸矫直技术以获得完美的平面度。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去应力退火，以确保良好的成型性能。

从以上介绍不难看出，亚麻花纹是奥托昆普外立面工程中最为常见的表层饰面。亚麻花纹凭借其非凡的质地经常受到建筑师的追捧。尽管在一定距离下，肉眼并不能分辨实际花纹，但跟非花纹材料相比，亚麻花纹材料看起来更均匀、更一致、更经典。漫射而非单一方向的光线为幕墙打造哑光效果。一小部分镜面反射光线则为亚麻花纹材料增添了熠熠发光的景象。

当然，除了亚麻外，奥托昆普还有更多表层产品可供选择。除了标准的 2B (退火和酸洗) 和 BA (光亮退火) 饰面外，奥托昆普还可以提供 25 种以上花纹的表层产品选择。其中最流行的是亚麻、方块、钻石、皮革纹、奥氏体、微型亚麻和烟雾。此外还可以在钢厂不锈钢卷板上浮雕全新的客户定制花纹。

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，进而决定了材料的最终外观。

奥托昆普还可提供被称为"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牌号2205 (1.4462)。 2205含有22%的铬、3%的钼和6%的镍。

奥托昆普还有一支擅长引导建筑客户的专案小组。他们甚至可以针对内外建筑面材的特殊要求，开发出量身定制的外、内用饰面。

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%[11,12,13]。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

uncoated metal cladding (regardless if it consists of stainless steel or aluminum) does fulfill this regulation and could therefore be attached to the façade of a building 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 major visual material 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 only just 0.2%. On the other hand, roughening leads to a dramatic increase of diffuse reflection. Therefore, no matter which roughness/gloss is adjusted on the façade material, the sum of specular and diffuse reflection (equals the "daylight reflectance") will approximately remain constant.

In conclusion, problematic for metallic sheets is the fact 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" and therefore can no longer come into consideration for façade applications.

It is also worth mentioning that the two glare problems which the posting of the Ministry of National Development refers to 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 of Frank O. Gehry's Walt Disney Concert Hall in downtown Los Angeles. Once again also 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. To our knowledge the stainless steel that Outokumpu has so far delivered to the various mentioned building projects has never caused any significant glare problems.

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. Outokumpu takes these incidents in London and Hong Kong very seriously and highly respects and understands the urge for regulations regarding reflectance. Luckily it seems that the Building and Construction Authority in Singapore has an open ear for Outokumpu's concerns and a case by case decision was indicated together with an accommodating statement concerning the maximum acceptable percentage value for the specular reflection.

New Developments

Due to this 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 this type 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 indwells stainless steel but simply in a damped down, overall duller appearing sheet.

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 (国际商务中心 ICC)，并将其作为更新反射率法规的引发契机[14]。然而，这个 20%"日光反射率"限制的后果是，使合适建筑面材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建筑面材都无法满足要求，因而再也无法附着到建筑物的外立面。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幕墙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，小比例眩光建筑面材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。据我们所知，奥托昆普迄今为止向上述各大建筑工程提供的不锈钢尚未造成任何严重眩光问题。

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。奥托昆普将严肃认真对待伦敦和香港发生的此类事件，高度尊重和理解有关反射率的立法动机。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，同时附署有关镜面反射可接受最大百分比值的采纳声明。

幕墙领域的新发展

鉴于新加坡当局所做的让步，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。

结论

不锈钢是复杂建筑构造的一流建筑面材，备受重视。本文介绍了奥托昆普在过去 20 年间完成的多项杰出的不锈钢外立面工程，深入分析了其最新活动，同时还介绍了奥托昆普针对外立面应用中的各种表层饰面材料。此外，文中讨论了新加坡有关外立面材料"日光反射率"的新限制，分析和质询了其对不锈钢板材造成的影响。在文章结尾处，介绍了奥托昆普当前研究活动的前景，希望为外立面应用开发出更具哑光效果的表层饰面。

Conclusion

Stainless Steel is a classy and much valued cladding material for sophisticated architecture. This article presented several distinguished façade projects with stainless steel that have been accomplished during the past 20 years and provided a detailed insight on current activities. The delivery range of applicable surface finishes for façades was presented. In this context, the high corrosion load in some Middle East countries was explained and the Duplex Grade 2205 was recommended for this region. Furthermore the new restrictions in Singapore concerning the "daylight reflection" of façade material were discussed and their consequences for stainless steel were analyzed and questioned. The article closed with an outlook on current research activities at Outokumpu to develop duller surface finishes for façade applications.