Title:	**Blades of Steel: Understanding the Limits of Metal Façade Design**
Author:	Patrick Loughran, Principal, Goettsch Partners
Subject:	Building Materials/Products
Keywords:	Façade Steel
Publication Date:	2014
Original Publication:	CTBUH 2014 Shanghai Conference Proceedings
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Blades of Steel: Understanding the Limits of Metal Façade Design

钢之刃：了解金属外墙设计的局限

Patrick Loughran

Patrick Loughran

Goettsch Partners
224 South Michigan Av, #1700
Chicago, Illinois
USA 60604

tel (电话): +1 : 312.356.0600
fax (传真): +1 312.356.0601
email (电子邮箱): ploughran@gpchicago.com
gpchicago.com

Patrick Loughran is a principal at Goettsch Partners, a noted façade expert and the author of two façade books: Falling Glass and Failed Stone. Licensed as both an architect and engineer, he serves in dedicated project roles and is a key member of the firm's Enclosures Group, an in-house team of professionals specializing in building envelopes and systems. He is a regular national presenter and has been quoted in The New York Times and served as the "glass expert" on the National Public Radio show "Wait Wait…Don't Tell Me!"

帕特里克•洛克伦是美国GP建筑设计有限公司董事之一，著名的外墙专家，及两本外墙书籍的作者:《坠落的玻璃》和《缺陷的石材》。持有建筑师和工程师的双重执照，他是一个对项目很有奉献精神的人，是该公司外墙小组——一个公司内部专门从事建筑围护结构和系统的专业团队——的关键成员。他每隔一段时间都会进行全国性的演讲，演讲内容曾被纽约时报引述，并在全国公共广播电台节目"慢着慢着……不要告诉我！"担任"玻璃界专家"。

Abstract

Metal claddings frequently skin our tall buildings. They provide the texture and shine that help distinguish one glass tower from the next. Like the fabric on a well-tailored suit, metal claddings provide the pleasing lines that ornament our façades; however, like a thread out of place, selecting the wrong metal for a façade can lead to imperfections that distract from the elegant appearance of our towers of steel. This paper discusses a variety of metals and the factors to consider when selecting a metal cladding system.

Keywords: Metal, Curtain wall, Corrosion, Pollution, Stainless Steel

摘要

金属幕墙常被用作我们高层建筑的表皮。它们所提供的质感和光泽，帮助区分不同的玻璃塔楼。就像在一个合身西装上的织物，金属幕墙对我们立面设计提供赏心悦目的线条装饰; 然而，就像一根不顺眼的线头，在外立面上选择了错误的金属可能导致缺陷，使我们美观大方的钢塔被瑕疵分散注意。本文讨论了各种金属和选择金属幕墙系统时需要考虑的因素。

关键词: 金属, 幕墙, 腐蚀, 污染, 不锈钢

Introduction

Architects inherently desire innovation in their designs; however, they often neglect to realize the limits of building materials. This paper will present information on the innovative metal use in tall building façades, identifying potential pitfalls and providing a practical guide on how to avoid them. Designers can become complacent with a preferred palette for cladding elements; however, a stainless steel façade suitable for a Chicago high-rise may not be as effective in the coastal region of Saudi Arabia. A copper screen wall designed for the clear skies of Helsinki may not be the best solution for the corrosive pollution found in Beijing. Different building environments require different metal cladding systems. This paper will address the fundamental pros and cons of using aluminum, carbon steel, stainless steel, copper, titanium and zinc. The goal is to identify which metals and finishes are best suited for coastal areas, deserts and cities with extreme pollution.

Aluminum

Probably the most prevalent metal cladding material, aluminum is relatively inexpensive, lightweight, and has a variety of strengths and hardness properties. Its major limitation is that it needs to be coated. Raw aluminum exposed to the elements will chalk up and discolor. This type of patina is not typically desired for a building façade.

序言

建筑师本身向往在其设计中反映创新; 然而，他们常忽略了了解建筑材料的限制。本文将介绍在高层建筑外墙中的创新金属应用信息，找出潜在的缺陷并提供有关如何避免它们的实用指引。对外墙包覆，设计师会自满于其一套特定喜好的外包覆元素搭配; 然而，一个适用于芝加哥高楼的不锈钢立面可能在沙特阿拉伯沿海地区并不实际。一个为赫尔辛基的晴朗天空而设计的铜屏风外墙在北京腐蚀性污染中可能不是最佳的解决方案。不同的建筑环境需要有不一样的金属幕墙系统。本文会讨论采用铝，碳钢，不锈钢，铜，钛及锌的基本优点和缺点。其目的是确认哪些金属及饰面是最适合沿海地区，沙漠和极端污染的城市。

铝

也许是最普遍的金属幕墙材料，铝是相对便宜，重量轻，并具有多种强度和硬度特性的金属。其主要局限性是它需要被涂覆。未经处理的铝材直接接触其它构件会白垩化和褪色。这种类型的锈迹通常不希望出现在建筑立面上。

铝涂层基本上分为两类: 液体或粉末涂于表面从而提供保护并上色。最好的液体涂料采用聚偏氟乙烯树脂 (floropolymer) 。聚偏氟乙烯 (PVDF) 液体涂料提供最佳的颜色选择，包括金属色类，并可通过采用一个较高浓度的金属小片来赋予一个丰富而有深度的外观。聚偏氟乙烯 (PVDF) 涂料在北美是较为常见，例如: 在芝加哥的水之塔 (Aqua Tower) ; 然而，在中国它们更常被应

Aluminum coatings are basically in two groups: Liquid or Powder which coat and protect the surface from corrosion and add color. The best liquid coating uses a PVDF (floropolymer) resin. PVDF liquid coatings offer the best selection of colors, including the metallic family, and are able to use a higher concentration of metal flake that gives a rich and deep appearance. PVDF coatings are more common in North America, for example: Aqua Tower, Chicago; however, they are frequently used in China. For example, the perforated aluminum cladding on the façade is Hotel Kapok Shenzhen Bay (19 stories tall) in Shenzhen completed in 2012 uses a 3-coat liquid PVDF metallic coating (see Figure 1).

Powder coatings are the second most common group for aluminum. These coatings are friendlier to the environment as they contain no solvent and emit the least amount of VOC's. Powder coatings can also use high performance PVDF resin. Other Powder coats use polyester powder coatings (PPC). These coatings are approaching the durability of liquid PVDF coatings (for example: the Shard, London). Both Powder and Liquid PVDF systems require a pre-treatment of the metal before applying the liquid paint or powder coating. This is critical to obtain the high level of aluminum corrosion resistance (AAMA 2605-05, seacoast testing).

Anodized aluminum is the third type of protection and is not a coating. Anodizing is an electrolytic surface treatment that increases the thickness of the natural protective oxide passive film that forms on the surface and improves corrosion resistance. The thickening of the passive film can also provide subtle colors to the metal. Porous anodizing treatments can also be dyed. This is the least expensive of the three typical aluminum surface treatments, but is limited to around eight different colors and is difficult to repair in the field. Anodized surfaces have better corrosion resistance then untreated raw aluminum but they are much less corrosion resistant then liquid or powder coatings. In polluted or salt laden environments it is critical to provide regular cleaning to remove these contaminants from the surface of the metal. For this reason, anodized aluminum is not recommended for polluted or heavily salted environments.

All three aluminum finish systems provide a range in durability for fairly aggressive environments; however, like most coatings, an aluminum coating can be worn off. Sand erosion can result in a loss in gloss and create an undesired sandblasted appearance or remove the protective coating entirely leaving it unprotected from corrosion. In abrasive conditions, like the sandstorms of a desert environment, sand erosion must be considered.

Recently there has been some attention to filiform, a type of crevice, corrosion on aluminum extrusions. The filiform is visible at a cut edge, and the corrosion is visible creeping up the extrusion from underneath the coating itself. A fabricator often purchases the extrusions pre-painted and in standard lengths, and then proceeds to cut the extrusions to specific dimensions. This results in the bare metal edge that provides entry to filiform corrosion. Coating manufacturers have recommendations on steps that can be taken to greatly reduce or eliminate the chance of filiform corrosion beginning by treating the cut edges.

With the exception of zinc, aluminum is more anodic then the other metals discussed in this paper (see Figure 10). Aluminum will sacrificially corrode if the conditions for galvanic corrosion exist (moisture and direct contact with other metals). The final consideration when selecting aluminum is thermal expansion. Aluminum expands at twice the rate of steels (including stainless) and the pure copper alloys typically used for cladding. For this reason, all cladding details must allow for thermal expansion of the metal.

Figure 1. Hotel Kapok Shenzhen Bay, Shenzhen 2012. 3-coat liquid, metallic PVDF coating on perforated aluminum panels. (Goettsch Partners)
图1. 深圳湾木棉花酒店，深圳，2012。穿孔铝板带3层液体金属性聚偏氟乙烯 (PVDF) 涂层。(美国GP建筑设计有限公司)

用。例如，在深圳于2012年落成的深圳湾木棉花酒店 (19层) 的外墙采用了3层液体聚偏氟乙烯 (PVDF) 金属性涂层的穿孔铝板外墙包覆 (参见图1) 。

粉末喷涂在铝材中是第二常见类型。这些喷涂是比较环保，因为它们不含溶剂并且散发的挥发性有机化合物 (VOC) 最少。粉末喷涂也可以使用高性能的聚偏氟乙烯 (PVDF) 树脂。其他粉末喷涂采用聚酯粉末涂料 (PPC) 。这些涂层已接近液体聚偏氟乙烯 (PVDF) 涂料的耐久性极限 (例如: 伦敦的碎片大厦the Shard) 。粉末和液体的聚偏氟乙烯 (PVDF) 系统在施加液体涂料或粉末喷涂之前需要一个金属预处理。这对获得高水平的铝材耐腐蚀性 (美国建筑制造商协会2605-05，海岸测试) 至关重要。

铝的阳极氧化是第三类型非涂层的保护。阳极氧化是通过对金属表面进行电解处理，增加在表面上所形成的天然保护性氧化物钝化膜的厚度，以此提高金属的耐腐蚀性。钝化膜的增厚也可为金属表面提供精细的颜色。可渗透的阳极氧化处理也可染上颜色。这是三种典型铝表面处理中最便宜的，但仅限于大约八种不同颜色，并且在工地现场难以修复。阳极氧化处理的表面较未处理的铝原料具有更好的耐腐蚀性，但相比液体或粉末涂料，它们的耐腐蚀性相对较弱。在受污染或含盐的环境中，提供定期清洗以从金属表面去除这些污染物就变得尤为重要。因此，于污染或盐度高的环境中不建议采用阳极氧化铝。

这三种铝材表面处理在相对恶劣的环境提供了一定程度的耐用性; 然而，像大多数涂料，铝涂层可被磨损消失。沙侵蚀可导致光泽度流失，并造成不期望的喷砂外观，或完全剥去保护涂层使其暴露于侵蚀环境。在磨蚀条件下，如沙漠环境中的沙尘暴，沙侵蚀必须加以考虑。

最近铝型材的一些纤维状缝隙类型的腐蚀引起关注。纤维状在切割边缘是可看见的，同时可以看到腐蚀从涂层下部向上渗透。制造商经常购买预先上色及标准长度的型材，然后将型材切割至特定尺寸。这导致金属边缘外露，并给纤维状腐蚀提供了入口。涂层生产商提供的步骤建议，通过对切割边缘的处理，可有效减少或消除纤维状腐蚀发生的机会。

相较本文所讨论的除了锌以外其它金属，铝具有更为活跃的阳极 (参见图10) 。如出现电偶腐蚀的条件 (水分和其他金属的直接

Steel

Carbon steel is used infrequently as a cladding element in tall buildings because of its heavy weight and its susceptibility to corrosion. Carbon steel discolors and corrodes in a wet environment; however, it can be coated to resist corrosion. There are a variety of high performance paint systems. When selecting a paint system, it is critical that the coating be applied over a properly prepared, abrasive-blasted or power tool cleaned surface covered with a zinc-rich primer. A comparison of the performance of the three most common paint system in terms of loss in gloss reveals the following ranking: polyurethane top coating is better than acrylic solvent-based enamel, with the acrylic water-based enamel being the worst performer.

Galvanizing is another coating system used for carbon steel. Galvanized steel is basically carbon steel with a layer of zinc and sometimes aluminum, which takes advantage of galvanic corrosion to sacrificially protect the carbon steel until the coating is lost. The process adds the longevity of steel in an exterior environment; however does not typically have the finished appearance desired for an exterior façade and provides limited protection in a salt-filled or polluted environment (see Figure 2).

A unique type of carbon steel that does not need to be coated is "weathering steel". Weathering steel is a type of steel that develops a rust-colored oxide film or patina that has a slower corrosion rate then carbon steel. Weathering steel (sometime referred to by the trade name COR-TEN ® steel) must be left unfinished in an exterior environment. Sometimes misunderstood, weathering steel is not rustproof and continues to corrode. In order to form the protective oxide, it must be exposed to regular wetting and drying cycles. It is not suitable for high moisture environments (high rainfall, regular fog, high humidity), where moisture will accumulate without drying, or coastal environments. For this reason, elimination of any surface crevices is important, and proper drainage of surfaces is critical to the detailing of this type of metal. Weathering steel's normal surface weathering can lead to rust stains on nearby surfaces. Like any metal patina, the details of the cladding should consider controlling water runoff to prevent staining of elements below. For example, the former Omni Coliseum, Atlanta, Georgia, built in 1972, never stopped rusting, and eventually large holes appeared in the façade. This was a major factor in the decision to demolish it just 25 years after it was constructed. The same thing can happen in environments laden with sea salt. Hawaii's Aloha Stadium is an example of a salt laden environment metal failure. A recent project that uses weathering steel, as a cladding element, is the United States Consulate, in Guangzhou, completed in 2011.

Stainless Steel

Stainless steel's material strength is similar to Carbon steel; however, unlike Carbon steel, stainless steel has a greater propensity to resist corrosion; much higher ductility, elongation, impact resistance, and better high temperature fire resistance. The thermal conductivity and expansion of stainless steel vary with the alloy family. Typically, the thermal expansion of stainless steel 304 and 316 is 40% more than carbon steel, while duplex 2205 stainless steel has similar thermal expansion properties to carbon steel. In addition, stainless steel comes at a higher cost. The cost of stainless steel depends on which type is specified. Type 304 is the most common for cladding elements and provides good corrosion resistance. Where moderate salts or industrial pollution are present, a slightly more expensive Type 316 stainless steel is usually suggested. Either stainless steel can be used in more corrosive environments if there will be regular cleaning. A recent project using a Type 316 linen finish stainless steel is the Park-Hyatt Guangzhou (66 stories), completed in 2014 (see Figure 7).

接触)，铝会发生牺牲性的阳极腐蚀。选择铝材最后需要考虑的是热膨胀。铝的热膨胀率是常用于幕墙的钢(包括不锈钢)及纯铜合金的两倍。由于这个原因，所有幕墙节点必须允许该金属的热膨胀。

钢

在高层建筑中，碳钢很少被使用作外墙包覆元素，因为其沉重的重量及对腐蚀的敏感性。碳钢在潮湿的环境中会变色及生锈; 但是，它可以被涂覆以抗腐蚀。市面上有各式各样的高性能涂料系统。当选择一种涂料系统时，上涂料前该表面需准备恰当，以磨蚀喷射或电动工具清洁表面，至关重要的一点是覆盖一层富锌底漆。三种最常见的油漆系统通过光泽损失的比较得到以下排名: 聚氨酯面漆比丙烯酸溶剂型瓷釉更好，带丙烯酸水性瓷釉是表现最差的。

镀锌是用于碳钢的另一种涂层系统。镀锌钢基本上是碳钢带有一层锌(有时是铝)，利用电偶腐蚀的特点，牺牲保护碳钢直到涂层丢失。这个过程增加了钢在室外环境中的寿命; 但是通常不具有可供外墙立面所需的成品外观，在高盐和污染的环境中仅能提供有限的保护(参见图2)。

"耐候钢"是一种不需要涂层保护的独特碳钢类型。对于耐候钢而言，钢材会在其表面形成一层锈色氧化膜或锈层，相比炭钢有更慢的腐蚀率。耐候钢(有时以商标名称为"考顿钢®")，必需在室外环境中保持未处理完成面。有时候会被误解，耐候钢其实是不会防锈并会继续生锈。为了形成保护性氧化，必须将其暴露于常规的湿润和干燥循环。它不适合于高水分环境(高降雨量，定期雾，高湿度)，当中的水分会积聚无法干掉，也不适于沿海环境。由于这个原因，消除表面裂缝是重要的，同时对于这类金属幕墙节点，合理的表面排水至关重要。耐候钢的正常表面风化会导致锈渍染污附近的表面。像任何金属锈层，包覆的节点应考虑控制水径流向，以防止其下方构件受染污。例如，前全运体育馆(Omni Coliseum)，亚特兰大，建于1972年，从未间断过生锈，并最终在立面上出现了大洞。这就是在它建成后25年决定拆除它的主要原因。同样的事情也可以在充满海盐的环境中发生。夏威夷的阿罗哈体育场(Aloha Stadium)是一个金属受含盐环境破坏的例子。最近的一个采用耐候钢作为外墙面板的案例是广州的美国领事馆，于2011年竣工。

不锈钢

不锈钢的强度与碳钢类似; 然而，不同于碳钢，不锈钢具有更大的耐腐蚀倾向; 更高的韧性，伸长率，耐冲击性，和更好的耐高温防火性能。不锈钢的热导率和膨胀会因合金的种类而有异。通常，304和316不锈钢的热膨胀比碳钢多40%，而双相2205不锈钢具有与碳钢相似的热膨胀特性。此外，不锈钢成本也较高。不锈钢的成本取决于所指定的类型。304型是最常见的面材，并提供良好的耐腐蚀性。凡有适度盐分或工业污染存在的地方，通常建

Figure 2. Galvanized Steel, Type 316 Stainless Steel and 2205 Stainless Steel bright annealed samples, Dubai Beach Site - 9, 12 and 21 months exposure with no cleaning. (Outokumpu / Nickel Institute)

图2. 镀锌钢，316型不锈钢和2205不锈钢亮退火样品，迪拜海滩，暴露于室外9、12与21个月没有清洗的状况。(奥托昆普/ 国际镍协会)

Although Type 316 stainless steel provides excellent corrosion resistance, it can discolor in a high salt or industrial pollution environment. Type 304 and 316 stainless steel comes in a variety of finishes and can be colored to give it the shine of gold or copper. 2205 duplex stainless steel is similar to or somewhat more expensive than Type 316. Its much greater resistance to salt and industrial pollution corrosion can minimize maintenance cleaning. The finishes are currently limited to linen, a finish that resembles glass bead blasting, and polished which makes the use of this metal type less frequent; however, because of the higher strength and superior corrosion resistance, this material can be considered to be used in a thinner gage than the other stainless steels (see Figure 9).

Other then titanium, stainless steel is the most noble of the metals discussed in this paper and, if it is in direct contact with other metals, it could accelerate their corrosion if that is not considered during design.

Copper

While essentially pure copper alloys are most commonly used for architecture, other alloys like the nickel silvers and Monel have been used as cladding elements offering raw metal colors ranging from orange to warm silver tones. As a cladding element, the close to pure copper alloys have a natural color, turns brown and then eventually takes on a green patina appearance. Copper can provide a wonderful patina for a building façade; however, it does have limitations for tall buildings. It does not have a high tensile strength (a fraction of high strength steels), can cause run off staining, and is often needs to be combined with other copper alloys (Brass and Bronze) to provide increased strength properties. It is higher in price than other metals and yet does have a limited corrosion resistance to salts. Corrosion maps are critical to determine how metals perform in a particular region (see Figure 3). Corrosion maps are available for most major cities. The maps reveal areas of low, medium and high environmental corrosivity for different materials and help to determine the thickness and required life span of a material in a particular environment. Copper has a similar thermal rate of expansion to austenitic stainless steels like 304 and 316. It is more noble than aluminum, carbon steel and zinc and must be separated from them to prevent galvanic action and accelerated corrosion of those metals (see Figure 10). It is less noble then stainless steel but, in all but the most severe environments, these metals are used in direct contact without a problem.

Titanium

Similar to Copper, Titanium is a chemical element. The two most useful properties of this metal are corrosion resistance, and the highest strength-to-density ratio of any metallic element. Titanium has a lower rate of thermal expansion than stainless steel, aluminum or copper. Although Titanium is similar to stainless steel in appearance, its main limitation is cost. Titanium is much more expensive than other metals and, for this reason, currently has limited use in tall building façades. One of the most notable uses of Titanium cladding is the Guggenheim Museum, completed in 1997 in Bilbao, Spain. Titanium can be combined with other metals like Zinc to provide better strength properties to these other metals.

Zinc

Zinc is more frequently used as a roofing element than a cladding element. The zinc roofing tradition can be attributed to the metal's durability in environments with no salt exposure. The roofs of Paris have been covered with this material for hundreds of years. Zinc develops a natural patina similar to copper. Zinc will turn from a shiny mill finish to a uniform gray over the course of two to five years. The

议采用稍贵的316型不锈钢。如有定期清洗，两种不锈钢均可应用在更侵蚀的环境。最近的一个采用316型布纹饰面不锈钢的项目是广州柏悦 (66层)，于2014年竣工 (参见图7)。

虽然316型不锈钢提供了优良的耐腐蚀性，在高盐量或工业污染的环境中它仍会褪色。304和316型不锈钢均有多种饰面，并可着色使其具有铜或金一样的光泽。2205双相不锈钢价格与316型类似或稍微昂贵。它有更佳的抗盐与工业污染腐蚀能力，并将维护清洗的数量减到最少。饰面目前只限于布纹 (饰面像玻璃珠喷砂) 和抛光，这让这种类型的金属在实际中应用较少; 然而，由于有较高的强度和优异的耐腐蚀性，这材料与其它不锈钢相比，可考虑使用更薄的厚度。(参见图9)

除了钛，不锈钢是本文章所讨论的金属中最昂贵的，如在设计过程中未详加考虑，使其与其他金属直接接触，不锈钢可加速其他金属的锈蚀。

Figure 3. Atmospheric corrosion map. Corrosion rates of Copper after six years of atmospheric exposure in Kuwait. (KISR, Kuwait Institute for Scientific Research)
图3. 大气腐蚀地图。六年后暴露在科威特大气的铜腐蚀速率。(KISR, 科威特科学学院)

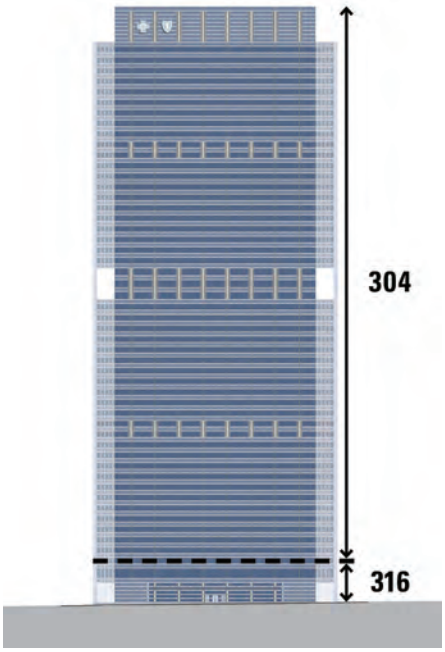

Figure 4. Blue Cross Blue Shield, Chicago, completed in 2010. Lower floors using 316 stainless steel with 304 stainless steel above. (Goettsch Partners)
图4. 蓝十字蓝盾总部，芝加哥，于2010年落成。低层采用316型不锈钢，上方为304型不锈钢。(美国GP建筑设计有限公司)

Figure 5. Blue Cross Blue Shield, Chicago, completed in 2010. Lower floors using 316 stainless steel with 304 stainless steel above. (Goettsch Partners)
图5. 蓝十字蓝盾总部，芝加哥，于2010年落成。低层采用316型不锈钢，上方为304型不锈钢。(美国GP建筑设计有限公司)

patina is actually a chemical reaction of the zinc with rainwater forming zinc hydroxide, and the addition of carbon dioxide or pollution. It is the most anodic metal discussed in this paper. If an environment is too corrosive for zinc, then it forms a chauky greyish white corrosion product with deep pits. Salts particularly increase its corrosion rate and only bare carbon and weathering steel are less corrosion resistant, but the heavier thicknesses used help to extend service life. Zinc is not used for many cladding elements because of its higher cost and low strength properties. A notable modern cladding system using zinc is the Jewish Museum, completed in 2001 in Berlin.

Factors to Consider when Selecting a Metal Cladding System

Salt

Airborne salinity refers to the gaseous and suspended salt contents found in the atmosphere. Coastal regions of the world contain a high airborne salinity. High salt content in the air can contribute to the corrosion of ferrous and non-ferrous metals. (see Figure 2) Coastal cities must consider the presence of salt when selecting a metal cladding system. Cities away from the coast are also susceptible to corrosions from salt. Deicing salts used to clear icing roads in the winter months can adversely affect the lower floors of our tall buildings. For this reason, Type 316 stainless steel (in lieu of Type 304) is typically used for the lower floors of buildings exposed to deicing salts. The Blue Cross Blue Shield Headquarters, completed in 2010 in Chicago, uses Type 316 linen finish stainless steel for the first two floors to prevent the salts from the deicing trucks from deteriorating the metal panels at the base of the building. Type 304 linen finish steel panels are used for the remainder of the 55-story office tower. (see Figures 4 and 5). All of the metal families discussed can potentially have pitting and crevice corrosion problems as the result of airborne salinity. The most severe salt environments are those with high levels of salt accumulation and enough moisture (i.e. fog, humidity, condensation, light rain) to constantly dampen the metal surface. Examples include coastal locations with minimal rain, coastal locations which only have light misty rain or fog, and those with particularly high deicing salt exposure. In these environments, type 316 stainless steel can show signs of discoloration (see Figure 8). The most corrosion resistant options are titanium and highly alloyed stainless steels. For these conditions, 2205 duplex stainless steel should be considered.

Rain

Many coastal regions feel the effect of salt; however, a great equalizer is heavy rain capable of naturally washing surfaces. Many cities have a natural cleaning mechanism in rain that washes away corrosive

铜

虽然基本上纯铜合金是最常用于建筑，其他合金(如镍银)和蒙耐合金已被用作建筑面材，原材料的颜色范围从橙色到暖银色都有，起初是接近于纯铜的自然色彩，之后变成了棕色，然后最终呈现出一种绿色锈层外观。在建筑立面上，铜可以提供一个美妙的古色; 然而，在高层建筑中它确实有限制。它不具有高拉伸强度(仅相当于高强度钢的一小部分)，可导致径流污染，并经常需要与其它铜合金(黄铜和青铜)结合，以提升强度特性。与其它金属相比，它的价格较高，对盐的抗腐蚀性能却较为有限。用腐蚀地图确认各种金属在特定区域的表现是至关重要的(参见图3)。大多数主要城市均有腐蚀地图可用。该地图揭示出对不同材料的低，中，高环境腐蚀性，并帮助确认在特定环境中材料的厚度和所需的寿命。铜具有与奥氏体不锈钢(如304与316型)类似的热膨胀率。相对于铝、碳钢和锌，铜的电位较高，必须与它们分隔，以防止电蚀作用及加速对这些金属的锈蚀(参见图10)。它不如不锈钢电位高，但是，除了最恶劣的环境，在所有情况下，这些金属被用于直接接触是没有问题的。

钛

类似铜，钛是一种化学元素。这种金属的两个最佳特性是耐腐蚀，和在所有金属元素中拥有最高的强度—密度比。相比不锈钢、铝或铜，钛有较低的热膨胀率。虽然钛外观上与不锈钢类似，它的主要限制就是成本。钛是比其他金属更昂贵，并且由于这个原因，当前限制了其在高层建筑外墙领域的应用。其中一个最显著的钛包覆应用是古根海姆博物馆，于1997年在西班牙毕尔巴鄂完成。钛可与其他金属(如锌)相结合，对这些金属提供更好的强度特性。

锌

相对于外墙面板，锌被更多的用于屋面。锌屋面传统可归因于在不含盐的环境中该金属的耐用性。巴黎的屋顶已被这材料覆盖了几百年。与铜类似，锌会形成一种自然锈层。在两到五年的过程中，锌会从一个闪亮的磨光完成面变为均匀的灰色。锈层实际上是锌与雨水形成的化学物质——氢氧化锌，并附加二氧化碳或污染。它是本文所讨论最为阳极的金属。如环境对锌太过侵蚀，则它形成带深坑的粉状灰白色锈蚀产物。盐特别增加其腐蚀速度，耐腐蚀性仅高于无涂层碳钢和耐候钢，但增加厚度有助延长其寿命。许多建筑不采用锌做面板，因为它的成本较高和强度性能较低。一个著名的现代锌板幕墙项目是犹太博物馆，于2001年在柏林落成。

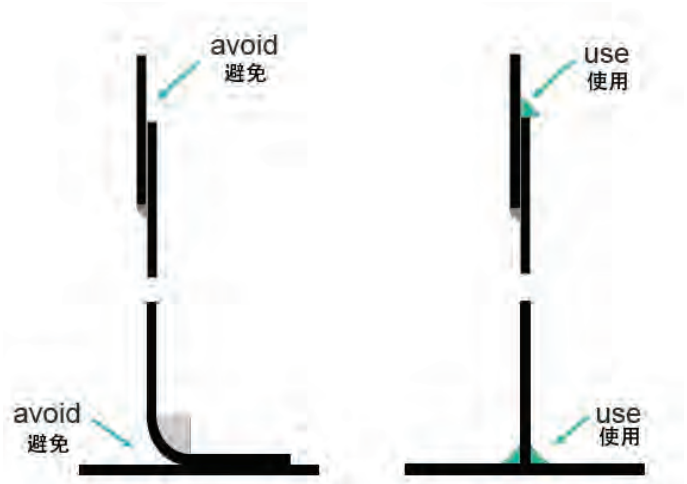

Figure 6. Combating Crevice Corrosion (Nickel Institute)
图6. 打击缝隙锈蚀 (国际镍协会)

elements on the face of our tall buildings. Certain regions of the world, for example the Middle East, have large towers constructed near salt waters; however, they do not have the benefit of adequate rain to rinse the salts off of the façade. Selection of the correct metal cladding is critical to maintaining the desired metal finish. If stainless steel is desired, 2205 Stainless Steel should be considered in areas with minimal rainfall where salt is present in the air or where building maintenance is difficult to provide. The King Abdulaziz Center for World Culture, Dhahran, Saudi Arabia plans to use 2205 stainless steel for its cladding system, expected to be completed in 2015.

Pollution

Many tall buildings are being constructed in developing nations where pollution runs high. Waking up in cities like Beijing, residents check the forecast for pollution levels for the day instead of the weather. Pollutants can contribute to the corrosion of metal cladding systems. Acid rain can deteriorate the finish of metals in a manner similar to salt. Combining high pollution with a coastal environment in a region that has little rain will create extremely severe conditions for metal corrosion. Atmospheric corrosion maps are critical in locating cities with extreme pollution conditions (see Figure 3).

Maintenance

Although pollutants and salts can attach to the skins of our buildings, a corrective agent to maintain a building's shine is regular cleaning. Many of the corrosive ills of metals can be cured through periodic cleaning. Regular maintenance can provide the long-lasting appearance of our metal claddings. In order to do this, designers must make sure all areas of a façade are easy to maintain. If portions of a façade are difficult to maintain, they will not likely be maintained and discoloration of the metal façade elements will follow.

Detailing

In addition to providing easy access for cleaning, good detailing provides an added benefit to metal cladding systems. Crevices in a building skin can provide places for water, salts, pollutants and sand to collect and permanently stain and corrode metals. Additionally, the corrosion rate of metals in tight crevices is higher then it is for the surrounding metal. Elimination of these crevices in the façade can greatly improve the appearance of the building (see Figure 6) and improve its corrosion performance. Horizontal metal surfaces should be avoided as they lead to the collection of dirt that can stain the façade after a rain. Sheltered metal surfaces on a building will go unwashed when it rains and must be accessible for regular cleaning in order to maintain the same appearance as the unsheltered areas.

Finish

Metals can be fabricated with a variety of surface finishes. Linen finishes to metal panels can contribute to the luster of a textured façade (see Figure 7). The finish of a metal surface can affect its durability. Surface roughness can add to the texture of a façade, but reduce its ability to stay clean and accumulations of corrosive salt and pollution are higher, increasing the corrosion rate. Smoother finishes are less likely to pick up dirt and contaminants and require less maintenance. Grain direction of uncoated metals can also help with maintenance. A strong horizontal grain surface is more likely to collect contaminants than a vertical or fine grain surface. Electro polishing of stainless steel provides one of the smoothest finishes possible for exterior decorative elements. This smooth surface minimizes the risk of contaminants forming.

选择金属幕墙系统时所需要考虑的因素

盐

空气中的盐度是指在大气中所发现的气态和悬浮盐含量。各地沿海区域的空气中含有高盐度。空气中的高盐含量可助长含铁和非含铁金属的腐蚀 (参见图2) 。在选择金属包覆系统时，沿海城市必须考虑盐的存在。远离海岸的城市也容易受到盐腐蚀。在冬季用于清除道路上结冰的除冰盐可对高层建筑的底部产生不利影响。出于这个原因，通常将316不锈钢 (代替304) 用于暴露在除冰盐的建筑物低层。在芝加哥的蓝十字蓝盾总部 (于2010年落成) ，将316布纹饰面不锈钢用于首两层，以防止除冰车上的盐腐蚀建筑物底部的金属板。304型布纹饰面钢板块用于55层办公大楼的其余部分 (参见图4和5) 。因大气中的盐分，导致所有讨论的金属类别均具有潜在的点状和缝隙腐蚀问题。最严峻的盐环境是那些高盐分积累水平和足以长期维持金属板湿润表面的水气 (如雾，湿度，结露，小雨) 。例子包括: 带少量雨水的海岸地区，或仅有轻烟雨或雾的沿海地区，以及那些特别多除冰盐的地方。在这些环境中，316型不锈钢可呈现变色的迹象 (参见图8) 。最耐腐蚀的选择是钛和高合金不锈钢。针对这些情况，应考虑2205双相不锈钢。

雨

很多沿海地区均感受到盐的影响; 然而，一个重要的均衡现象是大量雨水能自然地洗涤表面。许多城市拥有雨水这样的天然清洁机制洗去我们高层建筑立面上的腐蚀性元素。在世界某些地区，例如中东，在咸水水域附近有大型塔楼的兴建; 然而，它们没有足够的雨水可用来冲洗外墙上的盐。若要保持所期望的饰面效果，正确选择金属面材至关重要。如果希望采用不锈钢，在空气中含有盐分及极小降雨量或难以提供建筑物维护的地方，建议采用2205不锈钢。在沙特阿拉伯宰赫兰的阿卜杜勒阿齐兹王国世界文化中心，计划采用2205不锈钢作为外墙面板，预计于2015竣工。

污染

许多高楼大厦都在高污染的发展中国家兴建。在类似北京的城市，居民醒来时首先查询的是污染指数而不是天气指数。污染物可加速金属幕墙系统的腐蚀。酸雨可通过如盐一样的方式使金属饰面变质。沿海环境加上高污染的干旱区域，会造成对金属腐蚀极其严酷的条件。在查找极端污染的城市时，大气腐蚀地图就极为重要 (参见图3) 。

保养

虽然污染物和盐份可附着于建筑物的表面，但定期清洗是一个维持建筑物表面光泽的补救措施。许多金属的腐蚀性弊病可以通过定期清洁治愈。定期保养可以为金属幕墙提供持久的外观。为了做到这一点，设计者必须确保一个立面上所有区域都易于维护。

Figure 7. Park Hyatt Guangzhou – Type 316 linen finish stainless steel. (Goettsch Partners)

图7. 广州柏悦 – 316型布纹饰面不锈钢 (美国GP建筑设计有限公司)

Sand

Sandstorms in desert environments must be studied for cladding systems constructed in these regions. Paint coatings are susceptible to damage during sandstorms. Sand erosion results in a loss of gloss and a sandblasted appearance. As technologies improve, coatings have become harder; however, they can still be removed in an abrasive storm, and the refinishing of metals in the field can be difficult and costly. Stainless steel can be an excellent solution for cladding systems in a desert environment because this metal can be left uncoated.

Costs

It is easy to recommend expensive metal like Titanium and 2205 duplex stainless steel for cladding elements; however, it is harder to afford these metals for projects with limited budgets. Designers need to educate their clients on the limitation of metals used and the maintenance required to maintain their shine. It is not uncommon to use higher priced metals at the lower levels of our tall buildings with the understanding that these areas will be the most visible and easier to maintain. As metals with greater corrosion resistance are specified and used, their cost will decrease and they will be easier to obtain. Fabricator inexperience can sometimes have a greater impact on bid pricing than raw material cost of new materials. Metal producer involvement can be helpful.

Conclusion

Selecting the metal finish and alloy compatible with the environment is critical for maintaining the elegant appearance of our new tall buildings. The best location for a metal façade would be a non-coastal city, with low pollution, that did not require deicing in the winter and was regularly maintained (for example, a tower in Paris). Most alloys and coatings would work in this environment. The most challenging location for a metal façade would be coastal regions, in a polluted desert city, where the buildings are not maintained. 2205 Stainless Steel should be considered in this environment. Selecting the correct metal is critical to the long-term appearance and performance of our towering blades of steel.

Figure 8. 316 Bead Blasted Stainless steel - two months after installation, showing signs of corrosion, Doha, Qatar. (Catherine Houska, IMOA)
图8. 316型喷珠处理不锈钢: 安装后两个月，呈现出腐蚀迹象，多哈，卡塔尔。 （凯瑟琳•胡斯卡，国际钼业协会）

如立面上某一个部分难以维护，它们很可能将不会被保养，随之而来就是金属外墙元素的变色。

节点深化

除了方便清洗，好的节点也会为金属幕墙系统提供额外的好处。在建筑表面的缝隙可以积存水分，盐分，污染物和沙粒并永久污染及腐蚀金属。此外，在紧密缝隙处的金属腐蚀速率相较其四周更高。因此消除这些立面上的缝隙可大大改善建筑物的外观 (参见图6) 并改善其耐腐蚀性能。应避免水平向的金属表面，因为下雨后它们会积存污物并污染立面。在建筑物上被遮蔽的金属表面在下雨时不会被洗涤，这些位置应定期清洁以保持与无遮蔽的区域的相同外观。

表面处理

金属可以有多种表面处理方式。金属板上的布纹饰面有利于增强外立面纹理的光泽 (参见图7) 。一种金属表面的饰面可影响其幕墙系统的耐久性。表面粗糙度可添加外立面的质感，但降低其保持清洁的能力并积聚侵蚀性的盐和污染物，从而增加腐蚀速率。尘土和污染物不太可能附着于光滑的表面，因此所需的维护较少。在无涂层金属上的纹理方向也可以协助维护。一个粗糙的横向纹理表面比垂直或细微的纹理表面更容易积聚污染物。不锈钢电解抛光提供了外墙装饰元素中最平滑的饰面之一。这种光滑表面使污染物形成的风险最少化。

沙

沙漠环境中的沙尘暴是在这些地区兴建幕墙系统所必须研究的。油漆涂层在沙尘暴时很容易受到损害。风沙侵蚀导致失去光泽并呈现喷砂外观。随着技术的提高，涂料已变得更坚硬; 但在磨蚀的风暴中仍然会被分离，而且现场修补金属饰面是困难和昂贵的。不锈钢在沙漠环境中作为外墙面板可算是最佳解决方案，因为这种金属可以保留无涂层饰面。

成本

推荐昂贵的金属 (如钛和2205双相不锈钢) 为外墙面板是很容易的; 然而，在预算有限的项目中很难采购这些金属。设计师需要教给他们的客户有关金属使用的限制及维持其光泽所需维护等方面的知识。高层建筑的低层位置在视觉上较清晰且易于维护，因此在这些区域使用价格较高的金属面板就不会显得很特别。当具有更强的抗腐蚀性金属被指定和使用时，其成本将降低并更容易获得。加工者经验不足有时可以比新材料的原料成本在投标价格上的造成更大影响。金属生产商的参与也能有所帮助。

结论

选择与环境相兼容的表面处理与合金对于保持高层建筑的优雅外观至关重要。金属外墙的最佳位置将是一个非沿海城市，低污染，在冬季不需要除冰，并有定期维护的地点(例如，在巴黎的一个塔楼)。大多数合金和涂层会在这样的环境中生效。对于金属外墙最具挑战性的位置将是沿海地区，一个受污染的城市，在沙漠气候中建筑物未能受保养的地点。在这种环境中，建议使用2205不锈钢。选择正确的金属对我们高耸的"钢之刃"保持外观和性能尤其重要。

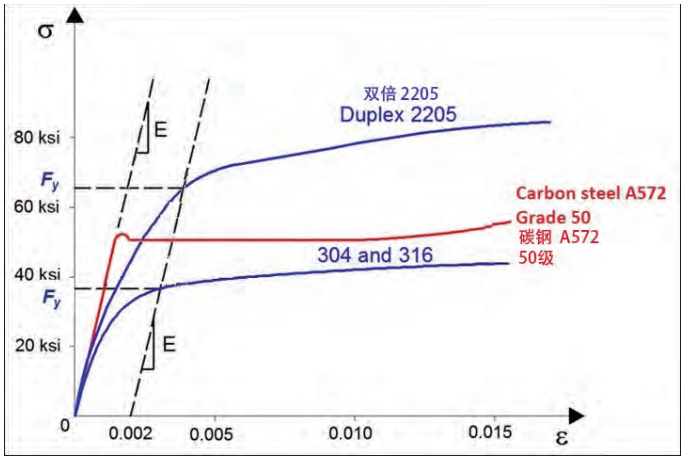

Figure 9. Stress Strain Comparison of Carbon Steel, 304, 316 and 2205 Stainless Steel. (AISC, American Institute of Steel Construction)
图9. 碳钢，304，316和2205不锈钢应力应变比较 (美国钢结构设计协会)

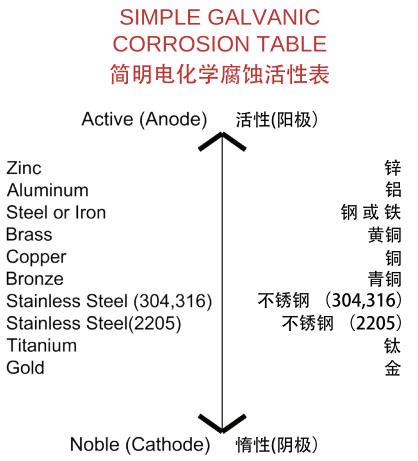

Figure 10. The further apart on the chart, the more dissimilar the metals are, and the higher the level of corrosion of the anode. (Goettsch Partners)
图10. 越不相似的金属，阳极腐蚀的程度就越高。 (美国GP建筑设计有限公司)

References (参考书目):

Donachie, M.J., Jr., 1988. **TITANIUM: A Technical Guide**. Metals Park, OH: ASM International. p. 11. ISBN 0-87170-309-2.

Harris, E,. 2012.. "Constructing a Façade Both Rugged and Rusty". **NY Times**,: (August 27). Retrieved 27 September 2013.

Heiderbach, R. H., "Marine Corrosion", **Metals Handbook Ninth Edn**, , Vol. 13: 893-918. ASM International.

Houska, C., 2007. "Designing on the Waterfront; Avoiding Corrosion Failures with Metal"; **The Construction Specifier**;:54-66.(Nov) <city/publisher>

Houksa, C., 2000. "Capabilities and Limitations of Architectural Metals: Part 1"; **The Construction Specifier**;: 1-7 (Oct) <city/publisher>

Houska, C, 2000, "Metals for Corrosion Resistance: Part II"; **The Construction Specifier**; : 8-14 (Nov).<city/publisher>

Nickel Institute, 2008. "Stainless Steels in Architecture, Building and Construction"; **Guidelines for Corrosion Prevention**; Reference Book Series No. 11 024; Sept 08/2.0.

Oka, Y., Sato, S., Kuriyama, N., 1993. **Application of stainless steel to the architectural exterior materials**" Innovation Stainless Steel Conference, Florence Italy, October 11-14,

Steel Construction Institute,, 1997. **Architect's Guide to Stainless Steel**, publication SCI-P-179. Berkshire, England.