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Paints in Extreme Exposures: Long-Term Durability and Cost Savings Throughout Building Life Cycle

极端严酷环境下的涂料保护：建筑全生命周期内的长效耐久和成本节约



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Abstract | 摘要

A protective coating is applied as a long term anti-corrosion method in steel protection; it can save the operation costs of buildings across entire life cycles, if the period to next maintenance can be prolonged 15 years or more. In high-rise buildings and luxurious hotels with dense populations in harsh environments, the paint economy will obviously influence the total cost. Using the Burj Al Arab Hotel as a case study, the long durability protection of a building via Baltoflake is illustrated, and the paint economic efficiency for buildings is analyzed under the life cycle cost analysis (LCCA) method. Many factors, such as access to repairs, shut down loss, and cooling cost reduction, should also be taken into consideration in the initial investment when a paint system is designed.

Keywords: 30 Years without Maintenance, Baltoflake, Building Whole Life Circle, Burj Al Brab Hotel, Cost Saving and Long Term Performance Paint

采用防护涂料是钢结构长效保护的方法之一，通过延长大修时间能够有效降低建筑全寿命周期的成本费用。特别是对于在严酷环境下，有着不小人员密度的超高层建筑和奢华酒店，油漆经济学对于成本的影响明显。采用迪拜帆船酒店作为案例，采用全寿命成本分析方法，阐述该项目中使用Baltoflake如何实现长效保护，分析了长效型防护涂料在节省成本方面的经济效益。在初始投资时，一些其他的重要因素，例如维修的可行性、停业损失和能耗降低也应在涂料方案制订时全面考虑。

关键词：30年免维修、Baltoflake、建筑全寿命周期、帆船酒店、成本节约、长效性能涂料

Long-Term Protection for Steel Structure in Buildings

Steel, due to its high tensile strength and low cost, is widely used in construction and other applications such as long-span structures (bridge and stadium roofing), light steel structures (workshops), and high-rising buildings. In corrosive environments, steel tends to react chemically with air and water. Lacking any inherent anti-corrosion properties, steel structures may rust both inside and outside, and even lose their structural strength, fail, and collapse.

It is reported that, globally, losses from steel corrosion can climb to 700 billion dollars, annually. According to statistics, economic losses from steel structure corrosion are approximately two to four percent of the Gross National Product (GNP) in several western developed countries (Yan Lin, 2005,P62). Moreover, corrosion accelerates under stress which can result in structural damage and collapse, and increase the risk of disastrous accidents. Frequent repair, maintenance, and even restoration should be considered when steel is significantly rusted. The indirect loss of business due to the

建筑钢结构的长效防护

由于钢结构的力学强度高，成本划算，在建筑物和其他领域，例如大跨度结构（桥梁和场馆的屋面结构），轻钢结构（厂房钢结构），和高层建筑（摩天大楼）中都获得了广泛的应用。但是钢铁暴露在腐蚀性的环境中，易于与空气中的氧气和水发生化学反应而生锈腐蚀。若缺乏一定的防腐保护措施，锈蚀可能会从里到外的发生，严重时还会使钢结构失去力学强度，甚至发生坍塌。

据报道，每年由于钢结构锈蚀带来的资产损失在全世界范围内高达700万美元。根据一些发达国家的数据统计，由于钢结构锈蚀产生的经济损失占国民生产总值的2—4%（林燕，2005，62页）。锈蚀在有力学荷载的钢结构建筑中会加速发生和扩散，更加容易导致结构性能的破坏和灾难性事件的发生。当钢结构锈蚀严重时，频繁的修补、维护甚至完全重新涂装就不可避免。由此带来的间接经济损失，比如停业停产导致的收益下降，可能数倍于修补费用这样的直接损失。

作为钢结构防腐蚀的有效方法，工业防腐蚀涂料可以长效地保护钢结构。如果我们能够使用设计寿命大于15年以上的高质量

downtime of an asset may be several times more than any additional costs incurred.

As a result, a protective coating can be applied as a long-term anti-corrosion method in steel protection. It can lead to a reduction in operation costs and extend a structure's lifetime, if the period to next maintenance can be prolonged up to 15 years or more. For buildings in harsh environments characterized by extreme exposures, a high-performance system providing exceptional protection should be designed and applied for long-term durability.

Paints Aesthetics and Economics in Buildings

When strolling the streets of our cities, people are unsurprisingly drawn to the unique architecture of our modern city landscape, including shopping malls, office buildings, and trade centers. Ingenious methods of structural design and architecture through the use of the very latest building materials and construction practices contribute greatly to the aesthetic appearance of the modern city. This is particularly the case for today's skyscrapers and luxury hotels, which rely heavily on advanced architecture coupled with enhanced decorative design to captivate their audiences. Amongst all the construction materials used in the creation of a modern building, the paint system is what clothes a building; in doing so, it provides the first impression to visitors and tourists.

Whilst color and gloss levels are key to the immediate aesthetic appearance of a structure, they cannot be considered in isolation. Consideration also needs to be given to the hardness and flexibility of the system. As decay and deterioration is inevitable, owners and architects need to give serious consideration to the severity of the environment the paint system will be subjected to and ensure that the paint manufacturers have taken such considerations into their research and development (R&D) when developing their paints. This is especially true in the case of more vivid color selections, like golden, bright red, and pink green paints.

Moreover, building owners and operators require their buildings to offer the same level of aesthetic beauty for many years after their initial opening; for this long-term performance requirement, the selection of materials and their application are critical. As such, building owners recognize that all attention should be made to capital as well as operational expense through developing a structured and

comprehensive approach to a maintenance and repair program throughout the service life of the structure.

Of course, the costs incurred through the lifespan of a structure can be more greatly managed by giving due attention to the whole life costs of the paint system, including: the methods of application, access to areas requiring future maintenance, the speed of application, and the speed at which products dry and cure. Reducing the project duration, whilst utilizing a healthy green approach to the project, will also result in an overall safer construction process.

Once buildings are open and in service, the ability to carry out major maintenance programs is hampered and restricted by access, and huge costs become a consequence of taking areas completely out of service for maintenance. The initial consideration to the painting system used is thus a real, long-term cost consideration to be made during the initial design period.

It is estimated that the value of paint is less than one percent of a total investment; however, its true economic value is far greater, given the important role it performs in ensuring long-term aesthetic beauty and appearance. Today's architects, structural design engineers, and owners must thereby ensure that due and warranted focus is placed on paint specification.

Paint Protection Overview of Burj Al Arab

The Gulf region is characterized by heavy UV light and a demanding coastal climate, challenging architects to look for solutions that will provide long-term, heavy-duty performance, excellent gloss, and color resistance to fight such conditions.

The third tallest hotel in the world, the Burj Al Arab, designed by multidisciplinary consultancy Atkins and led by architect Tom Wright, stands on an artificial island at a height of 321 meters. It is famous and readily recognizable from its unique shape, which is designed to mimic the sail of a ship. This seven-star luxury hotel offers guests the most extravagant experience that money can buy.

Since it opened in 1999 (after a five-year construction period), the steel has been subjected to extreme exposure and has stood the test of this rigorous off-shore coastal climate, still in good condition after 17 years. The 14,000 tons of steel, located both internally and externally to the building, were protected

涂料, 不仅能够提高钢结构建筑的使用寿命, 保障安全, 而且还能够大大降低在运营中的成本支出和费用。特别是针对极端严酷腐蚀环境下的建筑, 设计超长防护性能的油漆体系进行保护是十分有必要的。

建筑的涂料美学和经济学

当人们漫步在如今的现代城市中, 不出意料地会被城市中独特造型的建筑景观所吸引, 包括各式各样的购物中心、办公商务楼和贸易中心。这些精致优美的城市建筑, 往往来源于结构和建筑设计的独具创新, 通过现代最新的材料应用和工程技术得以实现。尤其是在一些地标性的摩天大楼和奢华酒店, 特别依靠建筑上的创意设计, 外加配合精美效果的装饰设计让观者流连忘返。

对于这类建筑而言, 在所有建筑材料中, 涂料产品是建筑的外衣, 往往给游客和到访者直观的第一印象。涂料的颜色和光泽对建筑结构的外观美学十分重要, 不能孤立地单独考虑, 需结合建筑整体进行设计 and 要求。同时, 涂料的机械硬度, 漆膜的柔韧性也同样需要注意。任何一种材料, 其性能的退化和衰减是不可避免的, 建筑物的业主和设计师需要对严酷环境下设计的油漆体系给予重视和关注, 确保油漆供应商通过研发和测试, 能够充分了解项目的需求, 提供满足性能的产品。当建筑物选择使用金色、鲜红色和嫩绿色等鲜艳颜色时, 涂料性能满足需求尤其需要注意。

业主和运营商总是希望自己的建筑能够在投入使用若干年后, 其外观效果仍然始终如一。所以出于长效保护的需要, 装饰材料的选择和正确施工应用就显得尤为重要。在建筑结构的整个服务周期中, 业主越来越认识到, 需要对资本支出和运营成本同样予以重视, 通过在设计阶段对后期维护保养计划进行系统全面的思考和准备对两者产生影响。

建筑全生命周期内的成本费用, 通过重视设计寿命内涂料系统的成本控制, 可以得到良好的管理。这些方法包括: 合理的施工方案, 未来维修区域的可行性, 施工速度, 产品干燥和固化速率等。此外采用绿色环保的施工方案缩短工程周期, 也能够确保工程建设过程更加安全。

一旦建筑开张并且投入使用, 维修的困难度和停高额费用, 都会影响和限制大修计划的执行。因此, 在建筑的初始设计阶段, 就应该将油漆涂料体系的设计作为长期成本的影响因素之一予以重视。

油漆涂料的投资成本往往不到整个项目投资1%, 但是若考虑到它对于建筑美学和外观的长效保护的重要作用, 其经济价值远远超过其投资金额的百分比。因此,



Figure 1. Golden columns in the lobby (Source: Jotun)
图1. 酒店大厅的金色柱 (来源: 佐敦)

by heavy-duty paint. The 67,000 square meters of steel was applied with a glass-flake, reinforced, unsaturated polyester coating called Baltoflake. APS Dubai, responsible for the coating application of the Burj Al Arab, and also the Burj Al Khalifa. The company had inspected this project last year and planned to carry out maintenance; however, there was not a mark on it, much to their pleasure, which is reported and backed by a testimonial from Graham Young, Managing Director of APS Dubai.

A super-durable powder coat named Corro-Coat PE-SDF, with colors in RAL 9016 and RAL 5015, was used for all of the curtain wall members on this project; it continues to withstand extreme levels of UV light, various levels of humidity, corrosion, and other environmental pollutants to preserve the building's strength and appearance after 17 years.

The extravagant gold columns at the Burj Al Arab are known throughout the world; indeed, most tourists entering the lobby assume the columns to be real gold. The gold, however, is not real, rather it is actually a golden decorative interior paint called Majestic Golden. The color and gloss retention rarely change, saving on the entire cost of building (Figure 1 and 2).

Due to the success of this hotel project, the Shanghai Tower located in Shanghai, China also chose the same selection of decorative products for their top restaurant, presenting the challenge of showing up its own reputation (Figure 3).

Challenge from Severe Environment

An excellent anti-corrosion strategy to preserve a building's integrity and vitality is



Figure 2. Another view of the golden columns in the lobby (Source: Jotun)
图2. 酒店大厅的金色柱的其它视角 (来源: 佐敦)

项目中的建筑工程师、结构工程师和业主, 若要获得未来的质量承诺, 需要重视涂料的设计文件和技术规格书。

帆船酒店的涂装保护概述

中东的海湾地区向来以强烈的紫外线照射和海洋腐蚀性环境著称, 使得设计师一直在寻找能够既满足长期重防腐需求, 又具有保持光泽和颜色性能的油漆方案来克服这样的严酷环境。由设计师Tom Wright和专业顾问Atkins设计的帆船酒店, 位于迪拜321 平米的人工岛上, 是全球第三高的酒店。它独特的外观, 像扬帆起航的船帆, 使其举世闻名并且具有鲜明的辨识度。这座7星级酒店能够提供能够人们能够想象到的所有奢华舒适的体验。

帆船酒店经过5年的建设时间, 1999年开业运营, 经受住了极端严酷环境和沿海腐蚀环境的考验, 服役17年后仍然性能完好。14,000吨钢结构不论室内室外都得到了重防腐涂料的有效保护, 其中67,000平方米采用了环氧玻璃鳞片聚酯产品Bltoflake。迪拜的APS公司, 此前负责帆船酒店和哈利法塔的涂装施工, 去年对项目组织了一次涂层质量勘验, 准备实施维修计划。但是让人惊喜的是, 在其检验报告中发现几乎没有找到涂层破损之处。这也获得了其总经理Graham Young的高度赞扬。

此外, 该项目幕墙构建上采用了颜色为RAL 9016 和 RAL 5015的超耐候粉末漆Corro-Coat PE-SDF。在过去17年中, 起到了抵抗紫外线暴晒, 抵御不同湿度、腐蚀环境和各类空气污染物的侵蚀。



Figure 3. Decorative paint in Shanghai Tower's top restaurant (Source: Jotun)
图3. 上海中心顶部餐厅的装饰漆效果 (来源: 佐敦)

not only to choose the right paint system, but also to fully consider application conditions, future maintenance, and environment friendliness. A coastal environment is defined as one of the more severe environments in ISO 12944 – the widely accepted international standard of reference for the protection of steel structures. Similarly, the NORSOK standard, developed by the Norwegian petroleum industry, is referenced for the vast majority of offshore and onshore projects as the standard of reference for steel protection.

In this case, both of these standards together, with consultation from the paint manufacturers, were utilized and referenced during the design stage. Jumeirah Group (owner) and Atkins (consultant) gave full consideration to the severity of the coastal environment in the Gulf and to the long service life expectancy from the coating system. The necessity of selecting specially formulated polyester is designed to deliver unique glass-flake reinforcement and impermeable protection of steel against abrasion and corrosion for such a hostile environment, which has high humidity and heavy salt spray erosion. Glass-flake paint had been proven as a successful paint system in marine and offshore markets for structures, such as offshore drilling rigs, deck areas, buried pipelines, jetties, piles, and buildings in extreme exposure.

Baltoflake is NORSOK approved and performs well in an ISO 12944 C5-M environment under its recommended thickness in paint system design (Figure 4). It has passed a two year (17,000 hours) accelerated test of salt spray to predict performance, which verifies its exceptional lifetime of more than 30 years without maintenance.

Owners and architects alike are impressed by the anti-corrosive properties and exceptional performance of the system's hard wearing and high glass-flake containing products. Extreme abrasion resistance is also needed to fight against sand blown by the wind near the sea.

Moreover, many other key issues should also be discussed with all project stakeholders (Figure 5) and solved before making the final decision on paint specification. The improper application of coatings will always result in their premature failure. The methods of application, access to areas requiring future maintenance, the speed of application, and the speed at which products dry and cure are also key factors to complete this iconic project. In this case, Baltoflake cannot guarantee a service life of 30 years without maintenance when lacking a recommended and specific working procedure.

Paint System for External Steel Columns and Supports 外部钢柱和支架油漆体系	Paint System for Exoskeleton Truss 外骨骼桁架油漆体系
Grit blast clean to BS 7079 Part A1 Sa2.5	ARC sprayed Aluminum
Glassflake polyester 600 microns DFT	Panguard Tie coat 40 microns DFT
Hardtop Polyurethane 50 microns DFT	Penguard HB M10 150 microns DFT
	Hardtop AS 50 microns DFT

Figure 4. Paint system for steel structure projection in Burj Al Arab (Source: Jotun)
图4. 帆船酒店的防腐油漆体系（来源：佐敦）

帆船酒店大厅内金光闪闪的柱子特别引人注目，大多数游客步入酒店大堂时，都会以为其外表镀的是真正的黄金。实际上，柱子上的金属效果是由金色的Majestic室内装饰漆涂料做出来的，其颜色的精准度和光泽保持性这些年过去了几乎没有变化，降低了酒店的运营成本（图1、2）。

鉴于该项目的成功运用，位于中国上海的摩天大楼上海中心，在其顶部的餐厅内选择了同样的定制化产品，延续着维护这座新地标性超高层建筑声誉的挑战（图3）。

严酷环境的挑战

为了持续展现建筑的完整性和活力，优异的防腐保护十分重要。但是涂料保护不仅只是选择合适的涂料产品就结束了，而是需要全面考虑施工环境情况和性能，未来维修的可行性和对环境的影响。

ISO 12944标准在全球范围内受到广泛认可，是钢结构防腐蚀设计的权威标准。在此标准中，沿海环境被定义为最严酷的腐蚀环境之一。类似的，由挪威石油标准化组织编撰的NORSOK标准，也在大量的沿海和离岸海洋环境工程中普遍被遵从。

此案例中，在咨询油漆供应商专业建议的基础上，以上两个标准在设计阶段作为设计标准得此执行。Jumeirah集团（业主）和Atkins（顾问）针对海湾地区沿海腐蚀环境，对油漆涂料的性能要求做了全面的考虑，满足其长效服务年限的要求。在如此高温和严重盐雾侵蚀的极端严酷环境下，含有玻璃鳞片特殊配方增强性能的聚酯涂料，能够提供钢结构耐磨损的致密保护，在船舶和海工领域，比如钻探设备、甲板区域、浸没埋地管道、码头、钢管桩和沿海建筑领域，玻璃鳞片油漆已获得广泛认可，具有大量的成功业绩以应对极端气候。

Baltoflake在ISO 12944 C5-M下，通过设计科学的涂层体系和膜厚，可以通过NORSOK的测试要求（图4）。该产品通过了2年（17,000年）加速盐雾试验来预计其寿命，可以证明它具有超过30年免维修的超长耐腐蚀性能。业主和设计师对其坚固的外观性能和高玻璃鳞片含量留下了

Role 职能	Company 公司
Owner 业主	Jumeirah Group
Designer Consultants 设计顾问	Atkins
Main Contractor 主承包商	Murray Roberts/ AlHabtoor JV
Steel Fabricator 钢铁加工	Eversendai
Applicator Steel 涂钢	APS Dubai

Figure 5. Main parties in contract chain (Source: Jotun)
图5. 合同链中的参与各方（来源：佐敦）

深刻印象，由此带来的优异的耐磨性能，可以有效对抗海边的风沙吹打和磨损。

在产品之外，决定油漆技术规格书之前，还有很多其他的关键因素需要与合同链中的参与各方（图5）充分讨论和沟通。不恰当的施工过程往往会导致过早的涂层失效。这些内容包括合理的施工方案，未来维修区域的可行性，施工速度，产品干燥和固化速率等。在此案例中，若没有科学、严谨、有针对性的施工工艺，Baltoflake是难以提供30年的超长性能保护的。

在实际施工过程中，快速干燥和更少油漆的施工道数意味着工期的节省。Baltoflake能够在竖直钢板表面单道涂层一次性喷涂做到1500微米没有任何流挂，在仅仅施工完3小时之后就能够承受踩踏行走。这两个性能是有助于快速地将钢结构在工厂喷涂施工后转移到现场。Baltoflake是无溶剂的产品，具有优异的防水，耐化学品、溶剂、磨损和抗冲击等机械性能。其无溶剂的产品特性，极大的减小了有害物质的释放，有利于环境保护。

因此，涂料供应商在钢结构制作和加工过程中提供详尽的涂装技术支持十分的关键。他们可以严格按照相关标准，协助完成符合要求的表面处理和施工效果。项目需要选择满足资质和能力的涂装施工方。两家单位需要根据工程进度安排，紧密地与总包公司开展合作，确保按时交付。涂料施工过程的典型工序和部位图片请见图6-10。

总之，建筑的一个超长期防护涂层体系需要全面考虑以下方面：



Figure 6. Arc spray and paint application ongoing at yard (Source: Jotun)
图6. 外骨架钢结构在工厂车间施工电弧喷铝和油漆施工 (来源: 佐敦)



Figure 7. All steel wrapped in polyurethane (Source: Jotun)
图7. 所有钢结构外包覆聚氨酯胶带用来在运输过程中保护漆膜 (来源: 佐敦)

During application, fast drying and few coats means less downtime. Baltoflake can be sprayed in a single coat to give a dry film thickness of up to 1,500 microns on a vertical steel surface without sagging and can be walked on only three hours after application. That helps to transport coated steel from yard to site quickly. Baltoflake is a solvent free coating providing protection against water, chemicals, solvents, abrasion, or mechanical attack, and outperforming traditional protection products such as metallized and epoxy coatings.

During fabrication it is therefore essential that paint manufacturers provide qualified technical support to the project to ensure surface preparation and application is in full accordance with the relevant standards. A competent applicator was chosen for the project. The applicator and paint manufacturer worked closely with the main contractor to ensure on time delivery in accordance with the building schedule. Typical area and process records of paint application are in figures 6 to 10.

An exceptional durability paint system for buildings should be considered keeping in mind the following aspects:

- Appropriate standard
- Excellent performance meeting specific needs
- Technical working procedure considering local application condition
- Easy application properties such as fast dry, few coats
- Eco- friendly and good for health
- Quality Controlled with strict application and working procedure



Figure 8. Internal structure of sky view restaurant (Source: Jotun)
图8. 空中餐厅内部钢结构 (来源: 佐敦)



Figure 9. Helipad steel structures (Source: Jotun)
图9. 直升机起落架平台 (来源: 佐敦)



Figure 10. Burj al Arab under construction (Source: Jotun)
图10. 建设过程中的帆船酒店 (来源: 佐敦)

Long-Term Protection with Economic Efficiency

Many owners only care about the initial costs of construction, without enough attention to maintenance costs during service life, which will shorten the lifetime of the steel structure and rapidly increase the challenge related to repairs and operational costs, thus leading to the unsustainable development of buildings.

Life cycle cost analysis (LCCA) is a tool to determine the most cost-effective option among different competing alternatives to choose from (Ashworth, A. 1989, P. 8-11). In paint cost analysis, the basic principle is this: in the design and construction stages, superior protection as a preventive measure and repairs after failure are two competing alternatives after comparing cost and benefits. Owners or contractors should be considering the life cycle of a project and not just take the short-term perspective. Investment capital is composed of initial cost in new building and additional cost to meet design life requirements. It is more reasonable and competitive to design a paint system with an appropriate allocation of these two-part costs than traditional paint application; further, cost can be hard to estimate in many cases, regardless. Buildings should, therefore, be designed using long-term performance coating to reduce overhaul time during service life.

The steel protection in this hotel is characterized by a 30-year no-maintenance feature. That is an exceptional time period, as the maximum period per ISO 12944 is set at 15 years.

The total area of Baltoflake is 67,000 square meters in initial investment. If a normal epoxy paint system was chosen, the first investment cost could be 30 percent less; however, every five to eight years, the owner would be required to inspect the film condition and plan for repairs. Assuming the failure area is only five percent, then in the next 30 years, five to six repairs would be required and at least 30 percent of the area would be replaced by new paint, which makes the material cost quite similar theoretically, when compared to Baltoflake.

During each of these repairs, paint loss and application cost should also be taken into consideration with an estimated cost as the same as repairing paint. That means if USD\$1 million Baltoflake is assumed in initial construction, USD\$700,000 normal epoxy paint will be used at the same time, so it will be a repair and maintenance application cost of USD\$600,000; but, it will be only less

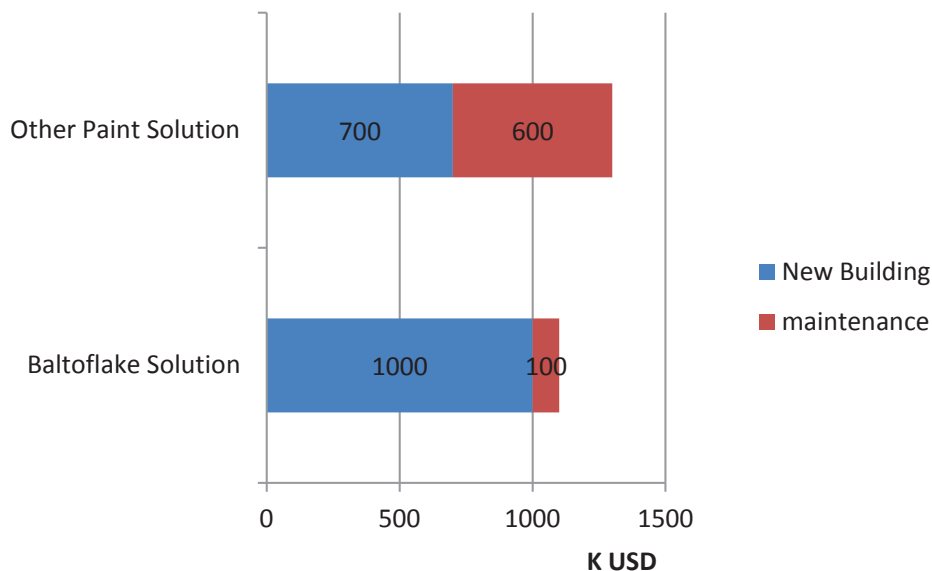


Figure 11. Cost analysis on coating solution in 30 years (Source: Jotun)

图11. 30年周期内油漆的成本费用分析 (来源: 佐敦)

than 10 percent initial cost for repairs using Baltoflake. It is very easy to calculate that the overall lifecycle cost of the Baltoflake results in economic savings to the project (Figure 11).

Use-cost per year is an important index to evaluate paint efficiency, and can be calculated as the following:

Use-cost per year= (Initial Cost+First Overhaul Cost+Shutdown Loss)/(Design Life)

It is obvious to find that use-cost per year reduces when paint design life is longer. Maintenance challenges such as hard to access areas and protection quality should be given appropriate consideration – more important than only placing the value on cost. Furthermore, the above does not take into consideration other negative aspects that maintenance would bring. Burj Al Arab is a famous icon throughout the world, and as a luxurious hotel it is frequented by thousands of tourists for accommodation and dining. The temporary shutdown required for repairs would not be acceptable to the owner as the financial loss would be substantially higher than the labor and paint cost. Secondly, the environment damage caused by paint application, VOCs, and other hazardous gas emission would further prove to be unfavorable for a shutdown. Another important issue for which costs can't be calculated is the disruption to guests at the hotel during any painting maintenance. A picture of a painter working with industrial paints and solvent coatings is not the image a seven-star hotel would like to portray.

If all costs are summarized over the life of the building, tangible and intangible, Baltoflake is a perfect solution and it likely offers savings of 50 percent of the paint budget when

- 适用的标准
- 针对具体需求选择性能优异性能的油漆
- 根据当地工程情况特点, 制定科学的施工工艺
- 便于施工的性能, 例如快干、涂层施工更少道数
- 环保要求
- 对施工工艺的严格执行和控制

长效保护的经济效率

许多业主只关心建设时的初始成本, 缺乏对全生命周期内维护保养的重视和关注。这种行为不仅会缩短钢结构的使用寿命, 还会大大增加后期维修的难度和运营成本, 而且也不符合可持续建筑的要求。

全生命周期成本分析 (LCCA) 是一个从各种可选方案中选择最具经济效益和成本的分析工具。(Ashworth, A., 1989, 8-11页)在涂料经济性分析中, 基本原则是: 在设计和建造阶段, 是选择“事先防护”, 还是选择“事后再修”, 是两个可选的方案, 需要做出经济上的比较。承建者需要对工程的全寿命负责到底, 而不是仅仅注重短期效益。项目的投资成本应该由新建项目的初始投资成本和服务周期内的追加费用组成。在设计油漆涂料体系时, 相比传统的油漆选择和应用, 更加经济合理的方式是在这两部分成本中进行有效的比例分配。未来的维护成本是难以预估的, 因此在初始建设时, 应更多考虑使用具有长效防护性能的油漆产品, 有助于在建筑全生命周期内尽可能降低大修的次数和首次大修的时间。

此案例中, 酒店的钢结构使用了30年免维修特点的产品进行保护, 这个防护的设计寿命是独一无二的, 远远高于ISO 12944标准内的最高防腐蚀寿命15年。



Figure 12. Burj Khalifa (Source: Jotun)
图9 哈利法塔（来源：佐敦）



Figure 13. The Louvre Museum in Abu Dhabi (Source: Jotun)
图10 阿布扎比卢浮宫分馆（来源：佐敦）

compared to normal paint systems. The scenario shown above is equally applicable to the use of a curtain wall powder coating. All the aluminum framework and members on high-rise buildings are difficult to repair with paint.

Other Cases with Cost-Effective and Long Lifetime Paint

There are two other examples with extreme exposures in harsh environments.

A total of 122,000 kilograms of powder coatings and 487,000 liters of paint have been used to decorate and protect the world's tallest tower, the Burj Khalifa, also located Dubai with a similar harsh environment (Figure 12).

This project required the use of a metallic matt finish powder coating to complement the aluminum for the 28,261 cladding panels that make up the exterior of the tower and its two annexes. On the other hand, coating

the 2,684-foot spire of the renowned tower is Baltoflake. The product was recommended and chosen by the client for its 30-year lifespan and minimal maintenance. The access to repair is the key issue for this skyscraper, so long-term lifespan and performance coatings on façade and steel are chosen as cost-effective products to ensure the structure's high quality.

Reducing the use of cooling systems and saving energy is another benefit of paint to save cost. High reflectance properties in powder products are formulated to reduce the temperature of aluminum building components that are exposed to the sun, thereby effectively contributing to lowering a building's energy consumption and cooling costs. The Louvre Museum in Abu Dhabi (Figure 13), with its bold design centered around a majestic dome structure, had a challenge in providing a comfortable experience for its visitors. Architects were looking to reduce the level of heat emitted by the dome structure and find an appropriate paint solution.

在该项目的建设过程中，在67,000 平方米的钢结构表面使用了Baltoflake。如果使用普通环氧体系油漆来保护，初始投资的成本可能会降低30%，但是每到5–8年，业主就会有需求进行涂层检查，并且作维修计划。假设每次失效的面积仅有5%，那么在30年内就会有5–6次大修，那么总计就会有30%的区域需要使用新涂层来替代。每次大修时相应的涂料损耗和施工人工成本也是一笔数量可观的成本支出，因为两者加起来基本和维修使用的涂料费用是差不多的。这就意味着，如果假设初始建设是若使用100万美元的Baltoflake，那么使用普通涂料的成本约70万美元，在整个生命周期内，维修材料费用加上维修人工费用加起来约60万美元。若使用Baltoflake带来的维护成本则会低于10%的初始投资。经过以上计算，我们可以很容易计算出使用长效涂料保护带来的成本上的节约（图11）。

年均涂料成本是衡量油漆经济性的重要指标，计算方法如下：

年均涂料成本=(初始成本+第一次大修成本+停业损失)/设计寿命

显而易见，随着油漆设计寿命的延长，年均涂料成本降低。此外，我们还要考虑维修的难度和维修后涂层性能质量的降低程度，这些远比仅仅接受维修费用的高的严重得多。

以上所有的成本分析都没有包含维修带来的负面影响。帆船酒店举世闻名，数亿千计的游客纷至沓来，主要是住宿和就餐。对于这样的豪华型酒店，即使是临时的停业维修对于业主来说也可能是不能接受的，因为停业带来的经济损失远远高于维修的成本和油漆成本。接下来我们讨论维修工程会带来对环境的负面影响，有机挥发物和其他有害气体的释放会延长停业整顿的时间。另一个无法估量的成本损失是由于维修导致游客对酒店声誉和印象的影响。油漆工人在施工味道很大的溶剂型油漆的场景，绝对不是一个七星级酒店想要让展现的。

如果考虑到建筑的全生命周期，将可见和非可见的成本都计算上，Baltoflake就是一个完美的解决方案，与普通油漆方案相比，它可以节省50%以上的成本。

以上方案的分析同样适用于幕墙的粉末涂料，而且在超高层建筑中铝型材框架和构建要使用油漆修补是十分困难的。

涂料长效性和经济性的其他案例

在相同类似严酷环境下，还有另外两个案例可以做出类似分析。

Conclusion

As a conclusion to this paper, the following list is offered as a summary of how to design for a long term durable paint system and save cost during a building's life time:

- 1. Exceptional durability paint should be designed according to the needs of customer and local environment;
- 2. Strict application control and technical work procedures lead to excellent performance;
- 3. LCCA can be taken into consideration for new buildings;
- 4. Long-term performance paint enhances the reputation of a building and reduces operation cost during service life; and
- 5. Access to repair, shut down loss, and cooling cost reduction can be factors to influence design decision when comparing initial costs and recurring operational expenses.

哈利法塔，同样位于迪拜，有着十分相似的腐蚀环境，总计122,000千克粉末涂料和487,000 公升钢结构油漆用于保护目前全世界最高的建筑（图12）。

该项目有28,261块幕墙板包覆在整个塔楼和附属群楼上，要求使用金属光泽粉末涂料来保护这些铝型材。在钢结构表面上，高达2,684 英尺的塔楼同样由Baltoflake来保护。考虑到长达30年的设计寿命能够极大的减少大修次数，业主和设计选择了这个产品。因为对于摩天大楼而言，维修的难度很大，甚至很多情况下是毫无办法的。所以长效型的粉末涂料和钢结构保护涂料就是确保高质量的最具性价比的方案。

涂料节约成本的益处还存在于可以减少建筑的空调系统，降低能耗。高反射性能的粉末涂料可以降低暴晒在日光下的铝型材表面温度，因此能够有效降低建筑的能源消耗。位于阿布扎比的卢浮宫分馆（图13）有着宏伟的中庭穹顶结构，考虑到要提供给游客舒适的体验，设计师在设计阶段就一直在寻找能够降低穹顶热量吸收的涂料方案。

结论

作为文章的结论，以下罗列了针对建筑的全生命周期来分析，如何设计长效涂料体系，节省成本支出：

- 1. 一个超长效的油漆涂层体系需要根据客户和项目环境的具体需求来进行设计。
- 2. 要想获得优质的性能保护，科学的施工工艺制定和严格的施工控制和监管是十分重要的。
- 3. 对建筑物进行油漆涂料的全寿命成本分析，长效型涂料能够有利于运营成本的降低，维护建筑声誉。
- 4. 相比于初始投资成本和后期维护成本，维修的困难程度，停业损失和对能耗的降低，油漆也可以是节省成本的因素。
- 5. 比较初始成本和经常性运营费用，维护、关闭损失、冷却成本降低可能是影响设计决策的因素。

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