MAXIMIZING CLEANROOM PERFORMANCE THROUGH ADVANCED COATING SYSTEMS

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Cleanrooms are becoming increasingly adopted across a spectrum of sectors – including in manufacturing operations for semiconductors, electric vehicle (EV) batteries, aerospace components, pharmaceuticals and other goods – helping ensure consistent product quality, regulatory compliance and a safe working environment for personnel.

Despite differences in industries, many cleanrooms share common features and qualities – allowing for control over environmental conditions, including temperature, static electricity, humidity and air pressure. Along with strict and specialized cleaning regimes, these facilities often minimize contamination with advanced air filtration for dust, particulates and microbes.

Coating systems are also fundamental components in cleanrooms, serving as barriers against contamination while withstanding the demanding conditions inherent to such controlled spaces. Key among the requirements of coatings systems are properties like non-particle shedding and non-outgassing – essential for stopping the entry of particulate matter and volatile organic compounds (VOCs).

A range of coating solutions – for walls, floors, ceilings and fireproofing – can help companies meet strict requirements and maximize their clean rooms effectiveness.

By partnering with experienced coatings professionals, facility owners can ensure the basic components of coatings used in cleanrooms are appropriate and effective in maintaining optimal cleanliness and product quality and safety. Coatings experts can provide guidance throughout the lifecycle of a facility – including selecting the most suitable coating systems for specific cleanroom requirements, taking into account factors such as cleanliness standards, environmental conditions and regulatory compliance.

CONTAMINATION CONTROL

In cleanrooms, controlling contamination is a central focus.

Each industry has guidelines for maintaining the required levels of cleanliness. Determining the appropriate type of cleanroom to meet these guidelines hinges on a range of factors – taking into account industry standards, regulations, cleaning feasibility, particulate concentration and others.

The International Organization for Standardization (ISO) has established specific cleanroom classifications to suit various cleanliness needs under the ISO 14644-1 standard. These nine classification levels are based on the maximum number and size of particulates allowed per cubic meter, with a Class 1 designation being the cleanest.

Generally, the semiconductor and microelectronics industries, demanding the highest cleanliness, utilize ISO 3 (Class 1) cleanrooms – due to the extreme sensitivity of electronic components to even minuscule contaminants. Temperature and humidity are also meticulously controlled within these spaces, as even slight variations can significantly impact product quality and yields. As will be discussed in a following section, flooring choices play a fundamental role in these environments, with options like electrostatic dissipative (ESD) flooring chosen for its ability to protect semiconductor components.

The aerospace industry relies mostly on ISO 4 (Class 10) standards. Contamination within these facilities can lead to equipment performance issues, which could lead to costly rework, downtime or failures. The effectiveness of aerospace cleanrooms relies on filtration efficiency, directed airflows, humidity control and ceiling fan coverage. Every detail is fine–tuned to reduce contamination and keep components safe.

In pharmaceutical or healthcare cleanrooms, where keeping airborne particles and microbes in check is crucial, coatings with antimicrobial properties stop bacteria from spreading on surfaces. In most cases, the pharmaceutical industry follows strict ISO 5 (Class 100) cleanroom standards to guarantee the purity and safety of medicines and other health–related products.

Maintaining exacting standards of cleanliness is also crucial in EV battery production. Cleanroom facilities that meet ISO class 5 or 6 standards are necessary for minimizing particulate contamination and creating optimal conditions and safety during the manufacture of lithium–ion battery cells. Battery module and pack assembly operations – which handle larger components – typically target ISO class 7 or 8 classifications. These facilities balance cleanliness criteria (such as minimal dust generation and airflow control) to maintain reliability throughout the manufacturing and assembly processes.

ISO 6 (Class 1,000) cleanrooms are also essential in medical device manufacturing, life sciences and operating rooms. ISO 7 (Class 10,000) cleanrooms find applications in drug compounding and cell culture industries.

In the automotive sector, ISO 8 (Class 100,000) cleanrooms are becoming more common. From original equipment manufacturers (OEMs) to certain tiers of suppliers, there's an increasing demand for cleanliness along the automotive value chain to ensure components meet the highest standards of precision, reliability and quality set by regulators – to ensure safety and performance for consumers.

FOCUS ON FLOORING

The Occupational Safety and Health Administration (OSHA) sets and enforces workplace safety standards to protect workers from occupational hazards.

Flooring systems play a vital role in maintaining the cleanliness and safety standards of cleanrooms. Generally, flooring in these facilities should be durable and easy to sanitize and clean – while contributing to the protection of assets and personnel.

There are a wide range of flooring systems tailored to fit the various demands of different industries. Providing effective static control, chemical resistance and slip resistance, floors need to cover a lot of ground.

High–solids epoxies are often favored for their chemical resistance to a broader range of chemicals than urethanes, as well as their greater durability in most cases, making them ideal for cleanrooms where stringent cleanliness standards and exposure to harsh chemicals are primary concerns. Their durability comes from their structural resin properties and system building capabilities, as a 250–mil epoxy mortar system is much more durable than a thin, 4–mil coat of a urethane. In addition, the excellent adhesion of epoxies to concrete substrates ensures a stable, long–lasting coating capable of enduring heavy foot traffic and equipment movement while upholding cleanliness standards.

However, epoxies may have longer cure times compared to urethanes, requiring more downtime during installation, and they may be less suitable for environments with extreme temperature fluctuations due to their susceptibility to becoming brittle at low temperatures and softening at high temperatures.

Urethanes offer a more flexible and versatile option for cleanroom floor coatings. While they may not match epoxies in terms of chemical resistance for most exposures, urethanes provide durability and can withstand moderate to heavy traffic. Interestingly, urethanes provide superior chemical resistance to the N-methyl-2-pyrrolidone (NMP) solvent used in EV battery manufacturing when compared to epoxies and are often used as a topcoat for an epoxy-based system, providing the added durability benefits of the base epoxy system with the appropriate chemical resistance in the urethane topcoat. Urethanes also exhibit better flexibility, which enables them to accommodate substrate movement and minor cracks without compromising the integrity of the coating. In addition, their faster cure times make them particularly appealing for cleanrooms where minimizing downtime is a priority, allowing for quicker return to service and reduced disruption to operations.

The superior ultraviolet (UV) light resistance of urethanes makes these coatings suitable for cleanrooms exposed to natural or artificial light, providing long-term protection against discoloration and degradation. That includes exposures to high-intensity UVC light, which is becoming more prevalent for sterilization purposes. Two-component acrylic urethane systems offer the best resistance to UV light, with broadcast systems featuring decorative aggregates that shield much of the resin from UV exposure performing best.

Water-based urethanes – and those with a polymer hybrid combination of urethane and epoxy resins – also offer a versatile solution suitable for various cleanroom applications. In some cleanroom environments, a complementary acrylic clear coat – low in VOCs and UV-resistant – can provide an added layer of protection while maintaining environmental standards.

To a lesser extent, other coating types can be used for cleanroom floors:

- Polyurea coatings are known for their rapid cure times, high durability and resistance to chemicals, making them suitable for cleanroom environments that require quick installation and robust protection against chemical exposure.
- Acrylic coatings offer good abrasion resistance and UV stability and are therefore suitable for cleanrooms that are exposed to natural or artificial light. They are typically used in environments with low to moderate traffic and where chemical resistance is not a primary concern.
- Polyaspartic coatings offer rapid curing times, similar to polyurea coatings, along with excellent UV resistance and durability. They are suitable for cleanrooms that require quick installation, UV protection, and resistance to abrasion and chemicals.

Each type of coating has advantages and limitations. Specific factors – including the requirements of the cleanroom, budgetary considerations, installation timeline and others – ultimately influence choices.

FLOORING FEATURES

Some cleanrooms, especially in semiconductor facilities, require static control flooring solutions which offer protection against electrostatic discharge. Features also include the application of a moisture vapor barrier (MVB) as a line of defense against moisture vapor transmission that can be detrimental to the clean room environment.

Another key component often utilized in cleanroom flooring systems is a cove or cant base (Figure 1), which creates a seamless transition between the floor and wall surfaces. This feature not only enhances aesthetic appeal but facilitates an ease of cleaning by ensuring that no gaps or crevices are present at wall-to-floor transitions where dirt, debris or microbial contaminants could accumulate.

Cleanrooms are subject to regular cleaning and disinfection of surfaces as a daily occurrence, and many different cleansers and methods are used. As newer methods are developed and used they can present new challenges to the protective finishes in these areas.

Therefore, seamless resinous flooring systems – both epoxies and urethanes, and combinations of the two – need to be durable and easily cleanable, while withstanding rigorous cleaning protocols, including exposure to harsh chemicals. Their seamless design also ensures that no water or cleaning agents can seep into gaps or joints, preventing potential contamination and maintaining the integrity and safety of the environment.

Scratch resistance is also a key quality that promotes longevity, reducing the potential for surface damage that could compromise cleanliness standards. This resilience contributes to the overall durability of the cleanroom environment, while also minimizing the risk of particle generation from surface abrasions.

Surfaces that are easy to clean save time on maintenance, boosting efficiency and productivity. Flooring systems should be built to last and environmentally sound. By cutting down on repairs and replacements, they should help save costs and promote sustainability efforts.

Figure 1. Cove bases create a seamless transition between floors and wall surfaces to enable ease of cleaning, as no gaps or crevices will exist where dirt, debris or microbial contaminants could accumulate.

MOST VALUABLE BARRIERS

Installing a moisture vapor mitigation system is essential for protecting cleanrooms and dry rooms in various facilities, including those designed for EV battery manufacturing.

These systems are directly applied to the substrate – usually concrete – and form a protective barrier between the slab and the lower layers of the floor coating. Vapor barrier primers are followed by epoxy or similar coatings, sealed with a polyurethane topcoat, offering multi–tiered defense against moisture infiltration.

As moisture vapor attempts to permeate through the concrete slab toward areas with drier and warmer air, these specialized coatings play a crucial role in preserving the strength and effectiveness of the flooring system.

It's critical to think about MVBs early on, especially during the capital expenditure (CapEx) phase of cleanroom construction. Ignoring this can cause headaches down the line, possibly disrupting operations. Well–installed concrete moisture vapor mitigation systems keep moisture levels managed, preventing any disruptions or hazards caused by humidity seeping into crucial areas.

ESD FLOORING SOLUTIONS

ESD flooring helps safely disperse static electricity. It's a staple in industries like semiconductor and electronics manufacturing – including EV batteries – aerospace and certain healthcare settings, where safeguarding sensitive equipment, materials and staff is of foremost importance.

If a cleanroom contains sensitive electronic equipment – or, if operations involve handling sensitive materials like explosives, flammable substances or dust – ESD flooring is likely necessary to prevent ignition and damage caused by electrostatic discharge. Especially in environments with low humidity – where static electricity tends to build up more, heightening the risk of explosions and similar hazards – ESD flooring provides extra protection by minimizing static buildup and potential sparks.

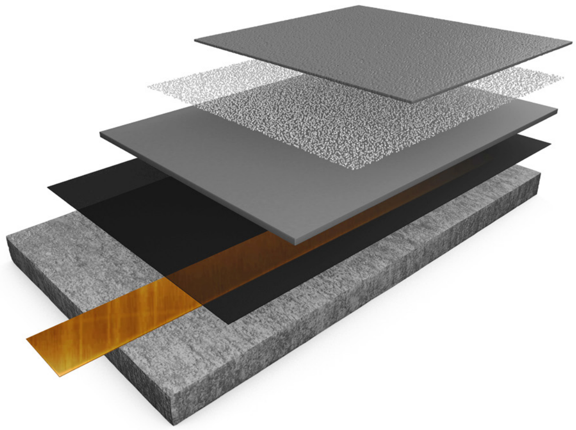

Figure 2. A common ESD flooring system includes the following layers applied on top of the concrete substrate:

1. Copper earthing tape
2. An ESD primer coat
3. An ESD epoxy build coat

4/5. An ESD urethane with a high wear additive

The coatings used in ESD flooring systems are made up of different key components (Figure 2), each playing a vital role in how well the system works overall. Crafted from materials such as rubber, polyurethane and epoxy, ESD flooring offers better resistance to voltage and protection against electrical surges compared to standard flooring choices.

Conductive materials – such as carbon or metal particles – tend to be integrated into the coatings to facilitate electrical conductivity, enabling static electricity to dissipate harmlessly through the flooring. In addition, copper grounding tape (Figure 3) is used within the conductive flooring layers and connected to a metal floor joist, steel post, the grounding terminal of an existing electrical outlet or another grounding point to dissipate electrical charges.

Polymeric binders, like epoxy resins or polyurethanes, create a strong, cohesive base that holds the conductive materials together and ensures the coating sticks well to the surface.

Mixing in fillers, additives, and static dissipative agents can also boost qualities such as resistance to wear and tear and certain chemicals. In places where insulating materials like carpets or plastics cover flooring, extra measures may be needed to control electrostatic discharge.

By carefully choosing and blending these components, facility owners can tailor ESD flooring coatings to match the specific needs of different situations, guaranteeing lasting performance and dependability.

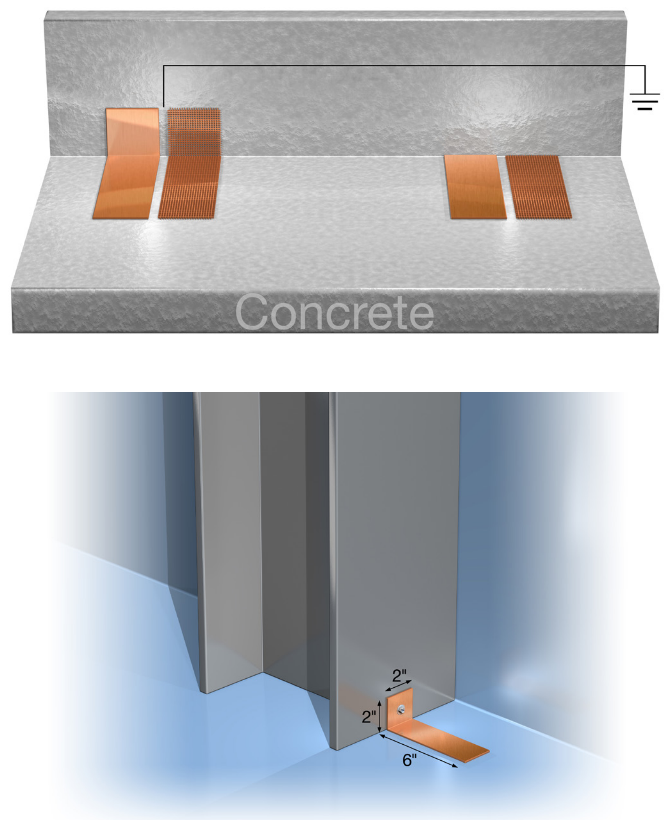

Figure 3. Establishing a direct, uninterrupted connection may be done by embedding copper tape within the flooring and connecting that to an existing electrical outlet (top) or another grounding point such as a steel post (bottom).

BOUNDARIES AND BARRIERS

In industrial cleanroom settings, walls can endure many forms of wear and tear, including harsh chemicals, moisture, impacts and abrasion. High-performance wall systems offer protection against long-term damage in these heavy-use environments.

Walls provide essential functions, providing imperviousness, ease of cleaning and resistance to moisture and microbial growth (Figure 4). Fiber-reinforced epoxy resin systems provide a protective barrier against most contaminants. Specifically designed for application to walls and ceilings, these systems can offer exceptional durability, ease of application and excellent performance properties, including resistance to UV light, which is atypical of traditional epoxy-based systems.

Smooth wall coating systems – with no pinholes or tiny gaps – should also be relatively easy to sanitize and maintain, with options available for power washing and resistance to vaporized hydrogen peroxide (VHP). With seamless surfaces that eliminate crevices where grime could accumulate, these systems are designed to inhibit the collection of dust, dirt, fluids and microbes.

Figure 4. Wall systems in sterile environments like cleanrooms need to be highly cleanable to minimize contamination potential, as well as durable to withstand the rigors of harsh cleaning protocols and prevent damage from impacts and abrasions.

Consisting of multiple layers, including epoxy and urethane topcoats, wall systems for cleanrooms should be engineered to resist cleaning regimens needed for certain service environments. They should help control humidity, minimize outgassing and prevent particle infiltration by being impermeable. These systems can include fiberglass-reinforced coatings for added impact resistance.

In semiconductor cleanrooms, for example, wall systems are critical for maintaining stringent cleanliness and environmental control standards necessary for manufacturing. These systems often feature multi-layered construction with epoxy and urethane topcoats to ensure durability and resistance to chemical and mechanical damage.

ESD mitigation features can also be integrated into wall systems in certain cleanroom environments to protect sensitive components and ensure operational reliability.

Cleanroom ceilings should offer exceptional resilience, including the durability to withstand daily washdowns. These systems could include two-component, water-based urethanes and a single-component, low-VOC, UV-resistant acrylic clear coat, which provides protection against corrosion from sanitizing agents and chemicals.

A breathable, water-based epoxy intermediate coat on ceilings could bolster durability and longevity. Together, these ceiling coatings can proactively address maintenance needs, which helps minimize downtime.

FIREPROOFING IN CLEANROOM ENVIRONMENTS

Fireproofing systems serve as a critical component of overall safety protocols within cleanroom facilities. Without adequate fireproofing, equipment damage, product loss and disruption of vital processes is more likely, which could create significant setbacks to productivity and profitability.

Additionally, cleanrooms have become more automated with new equipment now housed inside, include greater amounts of hazardous chemicals required for various production processes, require constant air flow and are larger. That all means there are more risks, and more employees at risk, making the safety benefits of passive fire protection (PFP) especially important in these areas.

Figure 5. Intumescent fire–resistive materials (IFRMs) meet requirements for outgassing, low dusting and environmental tolerances in cleanroom environments.

Steps taken to fireproof cleanrooms mainly focus on protecting the steel structure. The selection and application of fireproofing materials and systems should not introduce contaminants that could jeopardize sensitive processes.

Traditional spray–applied applied fire–resistive materials (SFRMs), while commonly used in other environments, can pose challenges in cleanroom environments due to the risk of creating dust. Generally, epoxy coatings are cleaner and more effective in these settings. Unlike SFRMs, epoxy coatings do not outgas or release airborne particulates, thus minimizing contamination risks.

The growth of EV battery facilities and semiconductor testing and packaging facilities has prompted a reassessment of how large cleanroom facilities are designed and constructed, especially when it comes to PFP in steel structures. Cementitious SFRM fireproofing, for instance, is not suitable for these types of environments because it can generate airborne particles and pose explosion risks if it falls off and comes into contact with chemicals used in battery production.

Specialized PFP solutions like intumescent fire–resistive materials (IFRMs), are preferred choices for their cleanliness and effectiveness in these environments (Figure 5). These materials meet demanding standards of modern manufacturing, especially in the production of EVs and their components. In addition, the coatings can be applied offsite (Figure 6), enhancing the quality of applications, minimizing overlap with other trades at the construction site to enhance safety and overall enabling faster project completions.

PARTNERING WITH PROFESSIONALS

Consulting with a coatings expert can help determine the most suitable options for particular cleanroom applications. From inception to execution, experienced coatings professionals can offer specialized expertise in addressing the unique challenges inherent to these complex facilities – from structural fire protection to protective coatings for walls, ceilings and floors.

Figure 6. Applying epoxy intumescent fireproofing off–site before constructing a cleanroom environment removes a host of on–site challenges.

These professionals, often from large coatings manufacturers and distributors, provide assistance during the specification phase and CapEx planning. In these partnerships, facility owners and managers can gain access to tailored features that optimize cost-efficiency, performance and compliance with industry standards.

These teams can also bring industry-specific insights and experience to the table – addressing niche requirements and optimizing coatings for applications such as the manufacturing of pharmaceutical products, EV batteries and semiconductor chips.

Coatings specialists can also provide ongoing support for cleanroom maintenance and project management. Their focus can extend to delivering maintenance coatings and project support, promoting the longevity and functionality of facilities.

AVOIDING AUDITS, FINES AND SHUTDOWNS

Partnerships with coatings experts can also help facilities ensure compliance with mandatory standards – essential for avoiding fines, shutdowns and audits – as non-compliance can lead to regulatory scrutiny and severe consequences. Regulatory agencies such as the U.S. Food and Drug Administration, ISO and others mandate strict adherence to guidelines to uphold product quality and safety.

Organizations that fail to meet these standards risk facing financial penalties, reputational damage and disruptions in production schedules. Put simply, following the rules isn't just about staying out of trouble.

Being proactive about following protocols saves facility owners from scrambling to fix things later and spending heavily on cleanup. Investing in cleanroom standards compliance also strengthens a company's competitive edge by demonstrating reliability and consistency in delivering high-quality products and services.

Teaming with experienced coatings suppliers helps facilities stay on the right side of the rules, reduces risks and sets up companies for lasting success.

OPTIMAL OPERATIONS

Sticking to cleanroom standards is essential for industries that depend on accuracy and dependability. Organizations can make sure their products are top-notch, keep their people and the public safe, lower the chances of running afoul of regulations and make their operations run smoother.

In many industries, as products become smaller and more complex, cleanroom requirements will likely become more stringent. Facilities will need to adapt to meet new standards and expectations to manufacture devices, components and food products. Coatings will continue to be a key component.

Flooring, wall and ceiling systems form strong barriers against contaminants, making surfaces easy to clean and resistant to microbial growth. ESD flooring helps prevent static discharge, safeguarding delicate equipment and personnel. Engineered wall systems offer insulation and shield against contaminants, with added features like moisture barriers and ESD protection further boosting reliability.

In essence, the right coatings are not just a finishing touch – they are the cornerstone of cleanroom success, safeguarding quality, efficiency and peace of mind for a diverse array of industries.

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FIGURES AND CAPTIONS

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