

Powder Coatings for AAMA 2604 and AAMA 2605 Applications

Gordon Inc.
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Purpose

The purpose of this paper is to explain the development and implementation completed to facilitate the powder coating of architectural aluminum components manufactured by Gordon, Inc. The coatings, preparations and application techniques are designed to conform to the AAMA 2604 and AAMA 2605 specifications.¹

The subject matter contained herein is the culmination of decades of experience; each section providing condensed, specialized knowledge to allow the reader to gain a comprehensive overview of each of the many facets of the coating materials, the architectural coating process, and subsequent performance.

A multi-generational evolution has led to the development of powder coating materials and application techniques producing finishes that are aesthetically pleasing, highly performing, ecologically sound, and economical. The process and materials, used by Gordon Inc., takes full advantage of these improvements to offer its customers the state-of-the-art in architectural coatings and performance.

The fundamentals and techniques expressed throughout this paper can be used to increase the knowledge base associated with high-performance architectural powder coatings, their application, and ultimate validation through rigorous testing. This paper is written to address audiences of three different perspective points of view; namely, architects, general contractors, and (building) owners.

Background

Liquid coatings have been used in architectural applications for more than two millennia. The need to protect vulnerable building materials from the elements has been a need recognized by mankind for a long time, and thus, has facilitated the continual improvement of coatings for that purpose. Powder coatings are an extension of this evolution, in that, they have been developed to improve the shortcomings of their liquid counterparts. Since both technologies co-exist, there is an inherent competition as to which is the “better choice” for a given application; as is the case for architectural.



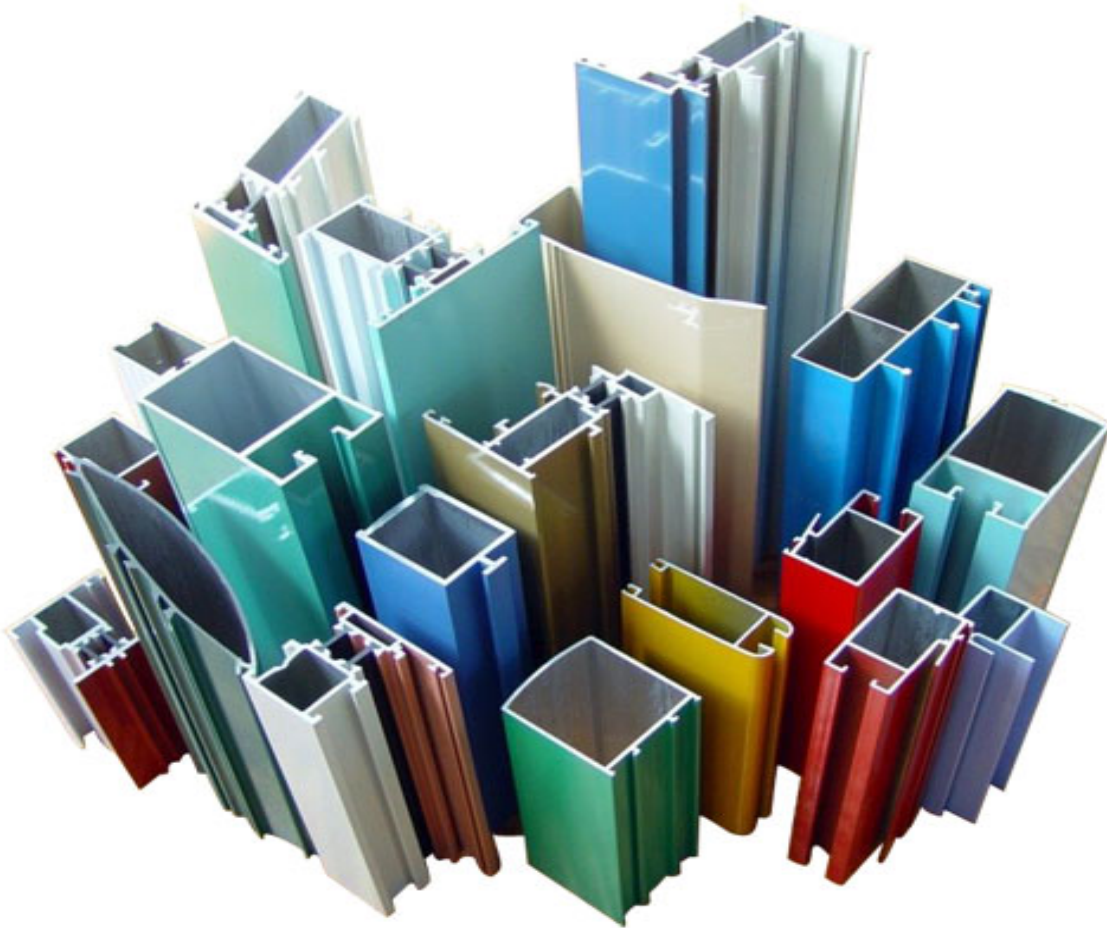
The Temple of Dendera, located in Egypt, exhibits an example of one of the world's oldest architectural coatings. These areas have been exposed to the elements for over 2,000 years and have survived admirably.

Powder coatings (thermoplastic) have been around since the 1940s and were initially developed as flame-sprayed coatings for certain limited applications. In the late 1960s, however, advances in electrostatic application equipment, as well as a growing ecological awareness, made powder coating more of a practical option in industrial finishing.^{2,3} By the late 1980s, there were powder coating alternatives becoming available for all of the most sophisticated liquid coatings, including those used in high-performance architectural finishing.

The liquid and powder coatings, as discussed here, are both organic in nature and are composed of nearly the same checklist of constituent materials: resins, curatives (hardeners), additives and pigments. Liquid coatings have an extra ingredient, that being solvent, which serves the purpose as carrier and diluent (viscosity modifier) allowing the transfer of the active ingredients from the application equipment to the substrate. By design, the solvent evaporates and allows the remaining material to dry and/or crosslink to enable curing.

Powder coatings, alternatively, use only air as a transfer media and to maintain space between the individual particles (atomize) as they are charged and deposited onto the substrate, thus transforming the powder into a fluid and allowing very manageable handling.

The types of powder coatings and associated applications are as numerous as those of their liquid counterparts. Powder coatings based on epoxy, polyester, polyurethane, acrylic and fluorocarbon chemistries are used in many markets (in addition to architectural) such as appliance, automotive, general industrial, scientific, decorative, agricultural, and pharmaceutical.



Powder-coated aluminum extrusions are a common staple in construction. Doors, windows, and curtain wall supporting systems, to name a few, are among the most common architectural applications.

Today, with sustainability becoming a high-priority initiative for many companies and industries, powder coating is more sought after than ever before. The absence of harmful VOCs (volatile organic compounds) and the nearly 97% material utilization capability, make powder coating the logical choice for industrial finishing.

Specifications

The coating of architectural aluminum has many associated specifications and guidelines that govern its preparation, coating performance, and handling. In the United States, these specifications are written and maintained by the American Architectural Manufacturers Association or AAMA, by which it is commonly referred.

AAMA was established in 1936 as an advocate for manufacturers and professionals in the fenestration industry and is dedicated to the promotion of quality window, door, curtain wall, storefront, and skylight products. Today, AAMA continues its mission for quality and actively works with manufacturers to continually improve their products by addressing technical and marketing needs, improving performance standards, and addressing regulatory issues that affect the industry.⁴

For our purposes here, we will focus specifically on AAMA specifications that are associated with high performance and superior performing organic coatings; AAMA 2604 and AAMA 2605, respectively. These specifications contain very detailed test methods and stipulate the required performance of each test. Sections 1.0 to 7.0 of each of these cover the foundational areas of the specification including the metal preparation and pretreatment. Section 8.0 and 9.0 cover the tests and test reporting. The performance testing will be covered in greater detail later in this paper.

The major differences between the AAMA 2604 and AAMA 2605 specifications are largely related to weathering exposure duration and corrosion resistance. AAMA 2604 is written for coatings that will see acceptable degradation over a five-year period whereas AAMA 2605 extends this to ten years. This duration refers to South Florida Exposure (section 8.9.1) in accordance with ASTM G7, which governs the method by which the exposure test is run.

There are several attributes of the coating film that are evaluated subsequent to the South Florida exposure test. Ultraviolet radiation that is contained in sunlight exerts force on the covalent bonds which hold the coating molecules together. Depending on the degree of exposure, these bonds begin to break and cause the compounds within the coating to fragment. These fragments can result in degradation to color retention, gloss retention, chalk resistance, and resistance to erosion and these effects are specified as a consequence to this exposure. (*See Appendix B*) This is particularly important to the long-term appearance of the coating and coatings manufacturers invest a significant amount of money each year testing their coatings as formulations continue to evolve.



Florida Site Climate Profile				
Latitude	Longitude	Elevation		
25° 27' North	80° 20' West	7.0 feet		
Typical Annual Solar Energy		TUV	Total	%Sun
Direct, 25° South (latitude angle)		280 MJ/m ²	6,588 MJ/m ²	69%
Temperature (Air)		C	F	
Average Summer Maximum		32°C	90°F	
Annual Average Maximum		28°C	82°F	
Annual Average Minimum		21°C	70°F	
Average		24°C	76°F	
Average Humidity		Rainfall		
Summer Max.	93% RH	Monthly Max.	237	9.5
Maximum	80% RH	Monthly Min.	46	1.8
Minimum	61% RH	Monthly Avg.	152	6.1
Annual	70% RH	Total/Year	1420	56.8
		Rain Days/Year: 111		

(Left) Test panels being evaluated at certified South Florida Laboratory. Note the 45-degree angle, Southward facing.
 (Right) A chart showing typical climate profile of South Florida. These conditions make it ideal for weathering exposure

The corrosion testing is also different between these two specifications. The AAMA 2604 specification utilizes ASTM B117 as the test method for corrosion testing. This test is a continuous exposure to a 5% salt fog that spans 3,000 hours. AAMA 2605 discontinued this testing method about ten years ago when the membership decided that ASTM G85, Annex A5, which is a cyclic test that, many felt, better represented the corrosion process in nature, especially in coastal environments. The duration of this test is 2,000 hours which is half of the exposure time utilizing the former test method. Evaluation of corrosion testing is done per ASTM D1654-08, *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*. Other differences between these two specifications are included in Appendix A.

Gordon Inc. has employed its own specification to supplement the AAMA specifications. The specification, “*Performance Specification for Architectural Powder Coatings*”, was written by Gordon, Inc. with the concurrence of Chemists and other Technologists to ensure its function and feasibility.⁵ The ultimate goal of this specification is to meet the respective AAMA specifications depending on the level of performance needed, but more importantly, to regulate the methodology by which this is done to remove variability of these coatings from different manufacturers. The Gordon Inc. specification accounts for different geographical corrosion zones, powder coating formulation guidelines, and many other specific physical and chemical attributes of the coating and coating film.

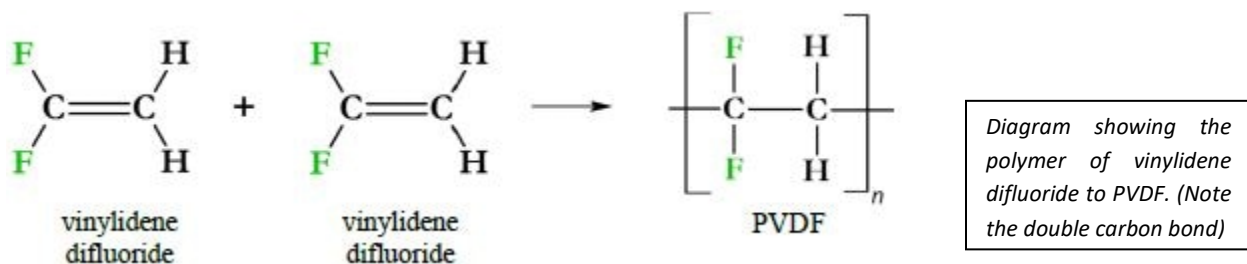
The specification also has provisions that contribute to the Total Quality Management of the organization by verifying and validating the quality of a coating before it is applied to parts. There are reporting requirements as well as mechanisms in place that promote the direct communication between Gordon, Inc. and its coating suppliers to verify quality and promote continual improvement.

Coating Chemistry

Liquid paint is one of mankind's oldest inventions dating back more than 40,000 years. The Egyptians painted walls of their prominent constructions 2,000 years ago and they still possess their vivid colors, even after being exposed to the elements for all of these years. During the industrial revolution, factory manufacturing of paints had become common. In 1866, the first paint ready for use from the can was invented. At this time, linseed oil was the main binder used in these coatings and people learned the functional benefits of applying paint to walls and other surfaces to protect them from their environment. World War II, however, created a shortage of linseed oil. This prompted the development of synthetic resins, which demonstrated great durability and color fastness. Resin development continued after the war leading to a number of resin chemistries and curing mechanisms.⁶

Polyester resin systems modified with silicone have been a successful class of durable architectural coatings for a number of years, as well as, polyurethanes and polyurethane blends. Many varieties of this are still used today for AAMA 2604 specified applications. It is important to note that these liquid coatings are categorically diluted with solvents that contain volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) which find their way into the atmosphere as a form of pollution. Their main purpose was to dissolve the binder (resin) of the paint and modify its viscosity such that it can be easily applied to the correct film thickness. Many of these coatings are baked-on, factory finishes that cure as a result of applied heat and subsequent crosslinking (thermoset).

In 1948, polyvinyl fluoride films were created and by 1965 widespread commercial use of a pigmented liquid coating had emerged. Through various licensing agreements and collaboration Polyvinylidene difluoride (PVDF) was born and had established itself as the basis of the highest performing architectural coatings of the day. The coating was sold under the tradename Kynar 500[®] and quickly became synonymous with a 70% PVDF content (by weight of the binder component).



There are other marketed versions of this coating as well as lower PVDF-concentrated (i.e. 50% PVDF) coatings that are applied and meet different levels of performance. Depending on the specific application or market need, Kynar[®] based liquid coatings can offer several options of

PVDF concentration and various blending resins. The most common blending resin is acrylic, and there can be several embodiments of acrylic resin depending on the coating requirements that are needed. Typically, AAMA 2605 is met by utilizing a 70% PVDF coating while AAMA 2604 can be met with 50% PVDF content.^{7,8}

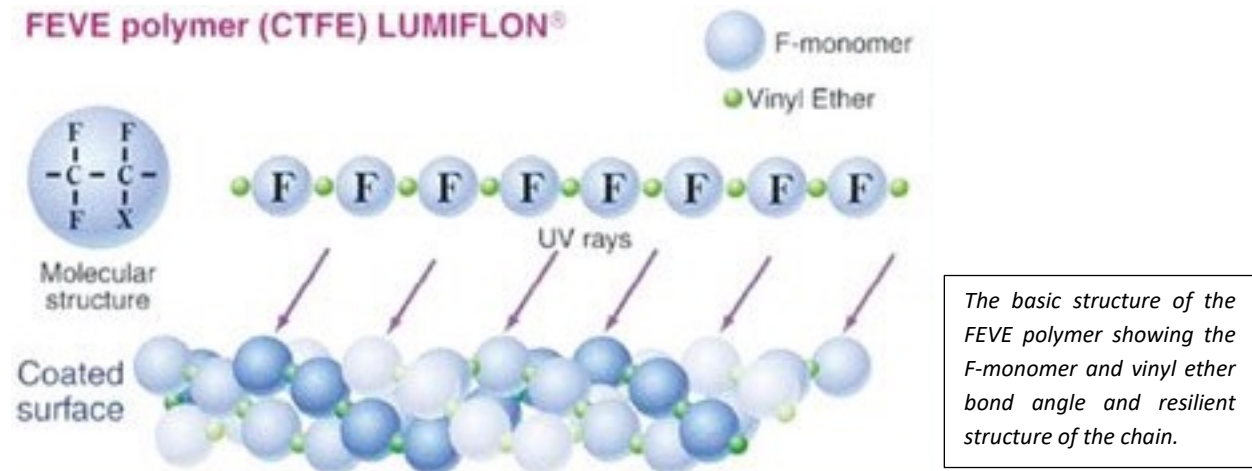
PVDF liquid coatings still represent the majority of high-performance architectural finishing products in the world. Powder coatings, however, continue to gain market share as concerns over solvent emissions, use of heavy metal pretreatments, and film hardness, to name a few, continue to be prevalent. As environmental awareness and regulations continue to gain momentum, more architects and building owners are specifying powder coatings for their projects.

Powder coatings, as mentioned earlier, are divided into two major classifications: thermoplastic and thermosetting. Thermoplastic powder coatings were the first coating powders to be used and were initially applied using flame-spray equipment. These powders, as the name suggests, can be sprayed onto a part and fused into a film through melting and cooling. This action can be repeated as heat is reapplied which softens the coating, much the way candle wax can be softened. Focusing on the phasal differences between powder coatings and liquid coatings and understanding that they both fulfill the same basic purpose; it must be understood that the molecular weight of each is different. A powder coating resin, in contrast to liquid, has a much higher molecular weight (M_w) allowing it to maintain its solid-state form. Based on this M_w a melting point between 130° F and 160° F is typical, such that the powder remains solid at ambient temperature, but can melt and flow at temperatures beyond.

Thermosetting powder coatings undergo a chemical reaction which crosslinks the resin with a curing agent to form an infusible, continuous film. The process involves the powder particles to go from a solid-state to a liquid-state and back to solid during the curing process. During the liquid-phase, the reactive groups are mobile and can assimilate to facilitate reaction and create much larger molecular compounds (polymers). The resulting film created during this process is very robust and will not soften in the way a thermoplastic compound will.

Thermosetting powder coatings were first developed in the United States in the late 1950s but only consisted of simple, dry-blended epoxy mixtures. It was not until 1961 that a West German company had the notion to process these materials continuously through an extruder, which is how powder coatings continue to be manufactured today. By the late 1960s, polyester resins for powder coatings were developed. Through a series of various embodiments and improvements, marketable, exterior durable coatings were appearing by the late 1970s and early 1980s.⁸ In the mid to late 1980s, super-durable polyester resins were becoming commercially available which enabled formulators to create coatings that would comply with AAMA 2604 (formerly AAMA 604).

In the late 1970s, a new coating resin for high-performance architectural thermosets was developed and became commercially available by 1982. The compound, Fluoroethylene Vinyl Ether (FEVE), is crosslinked with an aliphatic di-isocyanate curative. The Fluorine-Carbon bond in this polymer is the most robust covalent bond in polymer science. The strength of this bond resists the forces of UV radiation from natural sunlight providing decades of service for the resin system. These systems were put to work for applications requiring AAMA 2605 (formerly AAMA 605) by the mid-1990s once long-term exposure testing proved them worthy.⁹



FEVE resins are still the centerpiece of AAMA 2605 thermosetting powder coatings today, but the durability of these coatings, both liquid and powder, does not end with the resin system. All of the other components, specifically the pigments, must also be hyper-durable to endure the rigors of exterior architectural use.

The pigment portion of the AAMA 2605 powder coating will consist of white pigment (typical), inorganic tinting pigments which provide hue, and optionally, special effects pigments such as micas and metallic pigments. Organic pigments, even the best of breed, often break down around five to seven years of UV exposure. Simply put, organic pigments are typically bright in color and can be as diverse as the rainbow. While these materials are very attractive and cover a wide range of color space, they are not as durable as their inorganic counterparts. AAMA 2604 coatings can use certain organic pigments, provided they have been validated through long-term testing to the specification.

The white pigment, titanium dioxide (TiO_2), is typically present in all formulations, with the exception of clear, pure black, and certain metallic colors. The particular grade of TiO_2 used for both AAMA 2604 and AAMA 2605 coatings is of the highest quality available. It is manufactured with a protective coating, which is predominantly silica, and protects it from the damaging effects of ultraviolet radiation. Titanium dioxide is found in a plethora of products such as toothpaste,

sunscreen and electronic-grade ceramics. Roughly 80% of its consumption, however, is captured by coatings, paper, and plastics.



Titanium Dioxide, TiO_2 (left) and various mixed-metal oxide pigments used in the tinting of architectural coatings. These compounds have an extremely durable crystal lattice structure that resists the rigors of long-term weathering.

The tinting pigments, which work in conjunction with the TiO_2 , develop the actual hue (color) of the coating. Inorganic pigments, such as iron oxides and derivatives thereof, have very good exterior durability making them the appropriate choice for most architectural applications. This category of pigments while being extremely durable, are not as vibrant as organic pigments are. An extension of the inorganic family of pigments known as mixed-metal oxides (MMO) offers a much-improved color space that maintains adequate durability, meeting the requirements of AAMA 2605. These pigments are manufactured by the precise combining of metal ions along with other elements such as oxygen, silicon, phosphorous, and sulfur, then calcined at very high temperatures (1100° F to 2400° F). This manufacturing process results in a very inert, robust, crystal lattice that is extremely durable for chemical exposure and weathering making these an excellent choice for architectural coatings.

Metallic pigments and mica pigments are classified as special-effects pigments in that they impart a metallic appearance to the powder coating in which they are contained. These coatings have undergone much development and improvement over the last 30 years to the extent that many are single coat that perform admirably the AAMA specifications. One drawback in metallic powder coatings when compared to liquid is their ability to contain a “high” loading of special effects pigment. This leads to a weaker metallic appearance in powder coatings when compared to liquid. For example, powder coatings can contain up to about 6% of these pigments, by weight, while liquid can contain as much as 30% or more. This makes it a major challenge for powder formulators to match certain liquid colors.

The incorporation of these pigments into powder coatings normally involves an extra manufacturing process step. This step, known as bonding, is achieved by putting the powder coating material, as well as, the special effect pigment into a jacketed mixer. The mixer’s

temperature is put up to an elevated temperature, just below the melt point of the powder coating. Next, the mixer is activated and run at a certain speed for a specified amount of time. As the powder particles soften, the pigment particles can attach or “bond” to the powder. This process continues by quickly discharging the mixture into a cooling mixer and stirring at a slow speed until the powder is cooled to ambient. It is subsequently sieved and packaged for use.



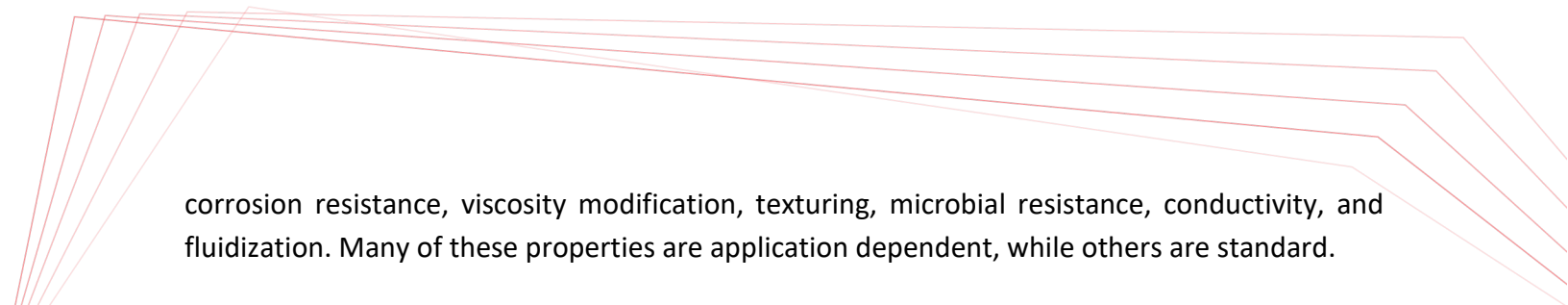
One version of a bonding machine. The bonding takes place in the upper round container while the cooling takes place in the long trough mixer.

Bonding creates a metallic-looking powder coating (i.e. silver, gold, bronze, etc.) that will spray much more consistently than non-bonded powders. If the pigments were only tumbled in, they would be allowed to separate in the application process and likely change color over a short period of time due to their differing electrostatic affinity as compared to their host powder coating.

The bonding process was created over 25 years ago to help create more consistent powder coating appearance, but more importantly, to make the use of aluminum powder pigments safe. Due to their small particle size, these pigments, under certain application conditions, can be quite explosive, so bonding is certainly a necessity when using aluminum pigments. Gordon Inc. only uses bonded materials when the need for metallic-effect coatings is specified.

It has been established that the binder system (resin + hardener) and pigments are the most responsible actors in the overall performance of the coating. The additive class of ingredients, however, can improve other properties of the coating, such as mechanical strength or processability, both of which are important, but cannot negatively impact long-term performance. An example of this would be the addition of a PTFE (Teflon) wax to improve scratch resistance, which it would certainly accomplish, however, another property, such as caulk adhesion, would be likely be negatively impacted. Formulation of architectural coatings involves a very delicate balancing act, to be sure.

Typically, additives make up less than 5% of the coating, by weight, but can augment certain coating properties in a major way. Some of the properties affected by the use of additives include over-bake resistance, flow, stain resistance, adhesion promotion, anti-gassing, enhanced



corrosion resistance, viscosity modification, texturing, microbial resistance, conductivity, and fluidization. Many of these properties are application dependent, while others are standard.

It is important that the paint manufacturer always be vigilant in its use of additives, especially in high-performance coatings. In some cases, the use of an additive to improve one property can lead to unintentional side effects, or diminished performance of another property. Gordon Inc. maintains an open dialogue with its coating suppliers to ensure that all-around performance is always maintained in its coating materials.

Aluminum Preparation

Architectural components can be made of many different types of metals, but for the purpose of this paper and the context of the referenced specifications, only aluminum will be discussed. The alloys of aluminum most common to architectural extrusion are in the 6xxx series in which aluminum is alloyed with Silicon and Magnesium. Alloys 6061 and 6063 are common in this application. Sheet goods that are intended for coating are typically made from the 3xxx series which is alloyed with Manganese while aluminum that is to be anodized comes from the 5xxx series and are mostly alloyed with Magnesium.

The preparation of aluminum involves cleaning, etching, and application of a conversion coating such that the adhesion of the coating is very strong. Good adhesion leads to the best long-term corrosion resistance, especially in highly corrosive environments such as areas of high industrial pollution or coastal areas. Gordon Inc. uses a dried-in-place coating for maximizing adhesion of the powder coating.

The main differentiator in aluminum preparation is whether or not the pretreatment system contains chrome. Chromate systems (containing hexavalent chrome) have a history dating back to the early 20th century coinciding with the use of aluminum for light weight aircraft parts. It has also been a mainstay for many years in preparing liquid-coated architectural components due to its ability in protecting various metals from corrosion.

Hexavalent chrome is a very dangerous substance, however, especially when airborne, due to its highly oxidative properties. It is a known carcinogen and in the 1970s, the EPA and OSHA began a series of regulations restricting the use and discharge of chrome-containing process water. In recent years, trivalent chrome has been evaluated as a “safer” substitute but has not achieved the full performance of hexavalent chrome and thus has seen limited use.

The typical schematic for chromate coating lines is either a washer (spray) system or a dipping system which employs 6-7 stages. The cleaning on these lines is typically acidic although some can be alkaline. The stages are as follows: (1) clean, (2) rinse, (3) deoxidize (typical for extrusions), (4) rinse, (5) chromate, (6) rinse, and (7) final rinse (typical for coil) which is typically a second chromate, although less aggressive than the first. The water from the rinse stages has to be treated on-site or carried away as hazardous waste.⁹

By 2000, successful uses of chrome-free pretreatments were being demonstrated on aluminum extrusion lines. This success in meeting AAMA specifications led to those applicators converting to the chrome-free technology.⁹ In contrast to the success stories, Liquid PVDF systems have experienced some difficulty passing AAMA 2605 consistently on non-chrome pretreated aluminum.

With the current version of AAMA 2605 including a cyclical corrosion test, which better simulates coastal environments, liquid PVDF coatings have had to stay married to chrome pretreatment due to its ease of use and consistency of results with the thermoplastic PVDF binder system. Custom coaters and many toll-coating coil lines of PVDF liquid coatings, however, have not made the switch due their use of multiple metals, which can be tough for chrome-free pretreatment to be effective. In addition to this, the modifications to the equipment needed to handle the aggressive (pH) chemicals provided another barrier to entry for many of these coaters.

In 2019, Gordon, Inc. built a new powder coating line with the ability to coat AAMA 2605 aluminum extrusion and sheet goods, using a five stage non-chrome system for pretreatment. This allows for an environmentally friendly system that can produce exquisite parts capable of ultra-high performance.

The washer/ pretreatment system uses 100% reverse osmosis (RO) water with less than 3 ppm impurity content. RO water is a foundational component of a high-performance pretreatment line. Many coaters use city water for their chemical baths and rinses. Through years of research and observation, Gordon Inc. concluded that city water could be very inconsistent. During the dry months of the year, water conductivity could get excessively high, and thus, leave deposits on the washed parts that would ultimately lead to adhesion issues. RO water eliminates this issue as it contains virtually no solids and has nearly zero conductivity. RO water also reduces the amount of chemicals needed to effectively charge the cleaning stages of the washer.

The five stages for cleaning are as follows: stage one, alkaline wash; stage 2, RO rinse; stage 3, acid etch; stage 4, RO rinse; and stage 5, dried-in-place polymeric conversion coating based on fluotitanic acid. The system provides nearly perfect test results as tested to the AAMA 2605 specification. In addition to this performance, it allows for an ecologically-sound process water effluent, which has been permitted by the local government water authority.

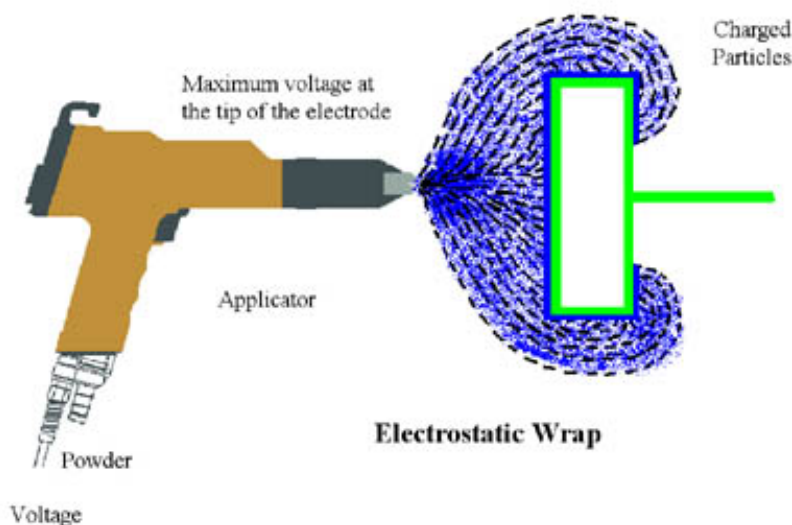
Application

Liquid paint equipment has been around for many years. The first spray gun for paint dates back to 1887 and was followed up by the first hand-held gun in 1907. More advances would follow over the coming decades. Improvements in pressure control, spray pattern variation, and faster color changing would contribute to modernizing finishing practices. In the 1980s, electrostatic liquid guns and HVLP (high volume, low pressure) equipment would further streamline liquid paint application.¹¹

There are other concerns involving liquid paint in a production environment. Liquid painting often requires mixing of multiple components. This can create instances where viscosity and other paint properties can change, affecting the application. In contrast, powder coatings, which are factory prepared, arrive at the coating line ready to spray which enhances the level of material consistency, reducing the number of rejected parts.

Calculating liquid coating utilization is also challenging due to solvent evaporation, but mainly by losses resulting from overspray. Varying part sizes, dimensions and line density all impact the amount of overspray experienced during application, which can negatively impact coating costs.

Powder coatings are applied mostly by electrostatic guns which create a corona cloud which imparts a negative electrical charge to the powder. The metal substrate has a positive ground which completes the circuit, thus creating the attraction of the powder to it. As mentioned in the background, electrostatic spray started in the early 1960s, and has undergone many improvements over the years.



This illustration shows the basic functionality of a corona-field powder coating gun. The powder particles are charged just beyond the spray tip of the gun where the corona cloud is generated. The particles are attracted to a positive ground which holds them in place until curing begins.

The fundamental mechanism of spraying powder has not changed very much since the beginning but the controls on the gun and ancillary equipment has realized several quantum leaps over the last fifty plus years. Regardless of the brand, or designed arrangement of the application equipment, there are several constants in spraying powder.

First, the powder must be mixed with air to cause it to fluidize. Once fluidized, it can be processed by the spray equipment via pumps, venturis, or other air manipulation. Once the powder is in motion, it is transferred through a gun which can further atomize the powder and ultimately create the condition by which an electrical charge is imparted to the particles. Today's sophisticated systems have fully computer-controlled hardware that allows the user to control a wide variety of conditions depending on the particular application that is being attempted. There is a great deal of automation which promotes consistency that is not easily accomplished by manual means.

Another feature of powder coating equipment, that is most differentiating as compared to liquid equipment, is that it can reclaim, or recycle, unused powder that is sprayed. Particles that are sprayed by the guns that don't transfer to the part can be collected via negative pressure, transferred through a sieve to remove objectionably sized or foreign particles, and re-enter the powder supply to be applied again. This recycling effectively utilizes 97+% of the powder loaded into the system. Liquid paint cannot be reclaimed in this way due to the fact that it sticks to any surface it lands on. If this surface is not the target part, the coating is lost forever. This reclaiming characteristic is coupled with quick-color-change capability which creates an opportunity to reclaim any size powder coating batch due to the small expense of time. Today's systems allow color changes to be performed in less than 10 minutes, in many cases. Gordon Inc.'s new powder coating line has state-of-the-art computer controls that can manage scores of coating recipes and implement these recipes as it recognizes parts that travel through highly discriminating optical detectors. This equipment also gives the operator the ability to make manual adjustments, if needed, to accommodate differences that can exist between different coatings. The line employs a dual cyclone for very efficient reclaiming of powder which allows about 97% utilization. This allows for much better material allocation, irrespective of part shapes and configurations, which

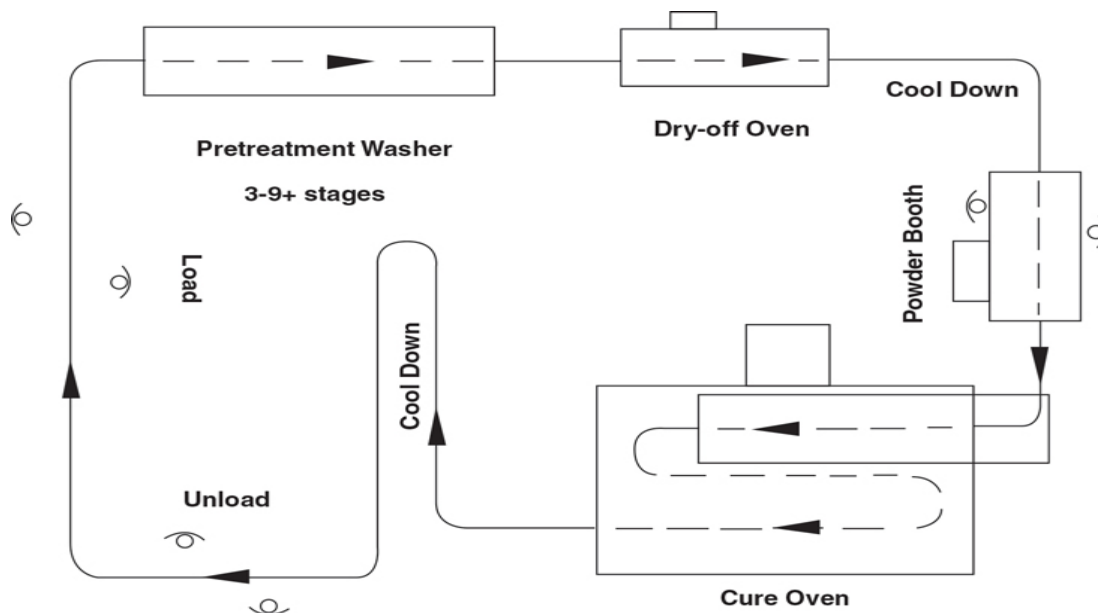


Gordon Inc.'s new application booth showing reciprocating guns applying an architectural powder coating on both sides of ceiling panels.

provides accurate estimation of coating material needed for a production run. Finally, the equipment allows fast color changes, thus minimizing down-time. This operation can be carried out in 10 to 14 minutes using one operator, depending on the difference of color.

In the practice of architectural coating that is in line with AAMA 2604 and AAMA 2605, most powder coatings applications require only one coat of powder. It is designed to be applied directly to clean, pretreated metal (in this case, aluminum) before being cured. Coastal applications requiring AAMA 2605 powder may further benefit by the addition of a primer, but that is typically considered on a case by case basis for enhanced corrosion resistance. Many AAMA 2604 and all AAMA 2605 liquid coated architectural applications require that a special primer be applied to the substrate first before the color coat can be applied.

After the application of the coating, be it liquid or powder, there must be a process by which the coating is cured. Generally speaking, architectural liquid coatings require force-cure; that is, they are typically put into an oven for a specified amount of time, at a specified temperature. Powder coatings must be exposed to heat, usually 400° F, such that the particles can melt, crosslink, coalesce, and solidify into a continuous film. This is most commonly achieved with a gas-fired, convection oven. These ovens, by design, manage the heated airflow through ductwork to create a balanced temperature throughout the oven. A well-balanced oven will have a temperature delta of 25° F or less from top to bottom. This ensures consistent cure and appearance for the parts being processed.



Schematic of a powder coating line configuration. (Courtesy of The Fabricator)

Liquid coatings, alike, will typically use this method of curing, however, liquid ovens have to recycle the air many more times to deal with the solvents that are evaporating as the coating

dries/cures. Kynar 500® requires a temperature of 450° F to 475° F to cure, which means that a much greater amount of energy is consumed to allow for the number of air turns and the ventilation of solvent fumes. It is important to note that the content of VOC and HAPS is higher in Kynar 500® than in many other industrial liquid paints. VOC is roughly 4.8 lbs. per gallon and HAPS content (after reduction with 20% Xylene) is about 3.7 lbs. per gallon. Many of the new and improved industrial and automotive finishes are in the 2.0 lbs. per gallon range, alternatively, but are not suited for architectural use.

A thermal oxidizer can assist in dealing with the significant air pollution that is created from these liquid finishes and help replenish the ventilated heat. Thermal oxidizers are expensive to operate due to their high operational temperatures which are in the range of 1800° F to 2200° F. These temperatures are needed to decompose the hazardous volatile organic compounds contained in liquid paint into CO₂ and H₂O.

Powder coatings typically do not contain VOCs, with the exception of certain AAMA 2605 coatings which can contain a trace amount of Xylene, which is less than 0.3%, by weight. This small amount does not warrant any special consideration regarding equipment nor does it require air permitting. Most powder coatings emit non-VOC/HAP compounds such as small amounts of CO₂ and H₂O as reaction byproducts.

The last advantage of powder coating, as it relates to application, is the ease and safety of cleaning. Powder coating booths and spray equipment are cleaned by compressed air, vacuuming, and dry wiping with lint free towels. Since powder presents itself as a dry residue, it is easily removed from booth surfaces and spray guns. The ability to “dry-clean” powder is a major attraction to those who have previously worked with liquid coatings.

Liquid paints require much more aggressive means of cleaning, including the use of harmful solvents, which contributes to the overall solvent use that is required to be reported. Solvents contribute to many health and safety issues for application personnel, who must handle these materials in the execution of their duties.

In summation, effective application is necessary for architectural coatings to fulfill their design intent. A well-designed powder coating facility will produce consistent parts that will perform to the designated level prescribed by the AAMA specifications. The economic and ecological advantages of powder coating are most prominent during the application process. In contrast to architectural liquid coatings, powder coatings do not have VOC containing solvents that have to be captured or oxidized. In addition, the coated parts do not contain heavy metals (chrome pretreatment) that necessitate special handling at the end of their service life.

Performance Testing

AAMA 2604 and AAMA 2605 have been mentioned throughout the body of this paper. In this section, performance testing will be discussed and some differences between the performance of liquid and powder coatings will be outlined. Conventionally, performance testing is carried out predominately by the coating manufacturer and reported to the applicator in an agreed-upon fashion. Some of this testing is very long-term in nature and is carried out by accredited, independent laboratories. (See Appendix B for AAMA 2604 and AAMA 2605 testing requirements and results.)

Gordon Inc. made a conscious decision, in conjunction with building the new powder coating line, that it would also procure the equipment and resources necessary to have a coatings laboratory. All of the Quality Assurance/Quality Control functions would be carried out in this laboratory as well as long-term corrosion testing and analytical testing necessary to maintain the quality of the washer/pretreatment system. This level of sophistication is unusual at most OEMs and paint application facilities. Many high-performance architectural coatings must be backed up by a warranty, and as such, Gordon Inc. realized the need to keep traceable documents that chronicled the test results of each architectural job that it coated.

The capabilities of the laboratory include all areas of the AAMA specifications with the exception of long-term weathering. This testing is appropriately performed in South Florida, as the conditions there have been standardized in extended weathering testing. This section will focus on testing that is done within the Gordon Inc. laboratory as well as testing that is done at independent or outside laboratories.

Performance testing at Gordon Inc. starts with Quality Assurance testing of incoming raw materials, in this case, powder coatings. As coatings are received, they are put into quarantine until they are released for use to the Coatings Team. Before a coating can be released for use, it must be reviewed for compliance to the Gordon Inc. Performance Specification for Architectural Powder Coatings. There are provisions in the specification for incoming batches of production powder. The powder coating supplier is required to submit three inch by five inch aluminum test panels that display the coating, a detailed color report that shows the color difference compared to the master standard, a particle size report that shows particle size distribution, and a Certificate of Compliance that shows other pertinent test results.

The tests that are relevant to application of the powder are particle size, powder fluidization index, sieve analysis, and surface conductivity (primers only). The particle size and fluidization properties are critical to the application success of powder coatings. Sieve analysis confirms that there are no over-sized particles in the batch which can cause surface defects on the parts. In the event that a primer is needed for corrosion performance enhancement, Gordon Inc. requires that

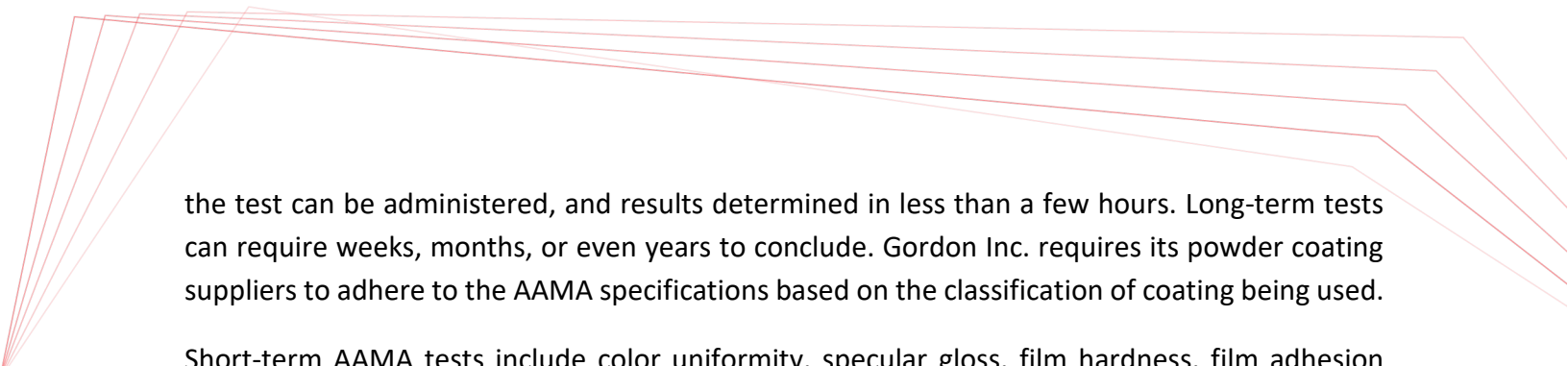
the primer have a minimum surface conductivity of $10^7 \Omega$ (ohms) so that the subsequent layers of powder will have adequate electrostatic attraction to the part to facilitate adequate film thickness.

Other tests are required to ensure the appearance of the powder coating meets expectations. The powder coating is applied to a test panel and cured under controlled laboratory conditions. Dry film thickness must be between 2.0 and 3.0 mils. Color and gloss are the initial characteristics that are evaluated followed by smoothness and over bake resistance. Gordon Inc. requires that the color be ≤ 1.0 units ΔE as calculated by the Hunter Equation using a digital spectrophotometer. The individual tristimulus values (green/red, yellow/blue, and dark/light) are also specified to prevent the total allowable color deviation to be present in only one axis. First article approval of color also requires that opacity also be checked for compliance to the Gordon Inc. specification. Full opacity (100% contrast ratio) of white coating should be at a film thickness of 2.5 mils; all other colors shall realize full opacity at 2.2 mils.

Gloss is specified to be $\pm 10\%$ of the target value measure at 60° with a certified gloss meter. Gloss will also be viewed visually, in some cases, if measuring anomalies occur. Smoothness of powder coated films is evaluated using the ACT smoothness panels which is a set of ten black panels numbered one to ten that range from a textured appearance (number 1) to an extremely smooth appearance (number 10). Gordon requires that the film smoothness be a minimum of a six rating for its non-metallic finishes and a minimum of a five rating for its metallic coatings. Over bake resistance depicts the coating's resistance to excessive time exposure to its cure temperature. Coatings must withstand 100% time overbake and show no change in color or gloss as a result of this exposure.

The last group of tests that are part of the incoming batch inspection combine chemical and mechanical tests. These tests will verify that powder cures correctly and has the correct mechanical strength. In this group of tests are impact resistance, flexibility, pencil hardness (scratch resistance), and solvent (MEK) resistance. Impact testing, per ASTM D2794, is a rapid deformation test. This test is specified by AAMA with a passing result of 3 mm of substrate deformation. This test can also be reported as inch-pounds of force. Flexibility is tested using a conical mandrel bend tester, per ASTM D523, and should resist cracking down to a radius of $\frac{1}{4}$ inch. Pencil Hardness, per ASTM D3363, should pass 3H for all architectural powder coatings. Solvent resistance is performed using MEK applied to a white cloth and rubbing back and forth with a 2-3-inch stroke length. Each forward and back motion constitutes a double rub. Cured powder coatings should withstand 50 double rubs without significant softening or film removal from the substrate.

The AAMA requirements are referenced within the Gordon specification and for the purpose of this paper will be categorized by short-term and long-term tests. Short-term basically means that



the test can be administered, and results determined in less than a few hours. Long-term tests can require weeks, months, or even years to conclude. Gordon Inc. requires its powder coating suppliers to adhere to the AAMA specifications based on the classification of coating being used.

Short-term AAMA tests include color uniformity, specular gloss, film hardness, film adhesion under three different conditions (dry, wet, and boiling water exposure), impact resistance, abrasion resistance, and chemical resistance. Long-term tests include corrosion testing (cyclic and non-cyclic), humidity resistance, and South Florida weathering resistance.

Coatings manufacturers that develop and produce architectural finishes must closely follow the testing protocol presented by AAMA. Many choose to qualify their coatings through independent, accredited laboratories, in addition to their own, for full validation of the coating's integrity. Gordon Inc. requires its powder coating suppliers to provide independent laboratory testing to validate the basis of design for AAMA 2604 and AAMA 2605 coatings. In addition, all manufacturers must have weathering tested through one of the accredited South Florida laboratories to verify UV resistance.

Gordon Inc. augments this testing in-house to ensure enduring quality in its coating process. For a comprehensive list of test methods used throughout the process, see Appendix C.

Conclusion

Gordon Inc. started powder coating twenty years ago to support a business acquisition that it had made. Over the next two decades, the powder coating process found its way into other areas of the business leading up to AAMA-grade applications. This created a need to upgrade and expand the powder coating process to accommodate the most demanding needs of the architectural industry. In 2019, a new powder coating line was designed and built that could certifiably perform to the requirements of AAMA 2604 and AAMA 2605 as well as improve quality, throughput, reliability, and capacity. Gordon Inc. is resolute in its decision to propagate the use of powder coatings for the high-performance architectural market. This resolution is what inspired the writing of this paper and to continue the mission of promoting powder coating as the only choice in our product finishing.

This paper has briefly spanned the history of coatings and their bearing on architectural applications. A sequential approach to the creation, application, and testing of architectural coatings has been presented showing the advantages and shortcomings of different technologies and materials. It is the intent of this paper to promote the use of powder coatings over liquid coatings for high-performance architectural applications. Powder coating, as described, most definitely has a shorter history than its liquid counterpart but has realized an accelerated evolution which got it to the performance that is required for many years of reliable service.

Both coating types must pass the same specifications; that is a given. The data shows that both perform to the expectation of AAMA's rigorous 2604 and 2605 guidelines. Since both coating technologies meet the specification, what are the other factors that should affect the decision on which coating type to specify?

The sequence of steps, as they relate to coating, quickly reveal that there are more benefits to powder coating than liquid coating. The coating itself, apart from the application process, is a great place to start. Typically, liquid coatings are received by applicators needing some amount of preparation, such as mixing to make it homogenous, combining different components to facilitate reaction, and/or even diluting with solvent to adjust viscosity. These activities lend themselves to variation which can affect coating performance and part consistency. Powder coatings, on the other hand, arrive at the applicator ready to use right out of the container. They are fully prepared at the factory under very controlled process conditions and must pass rigorous quality tests.

The pretreatment process that is commonly associated with liquid coating typically contains chromate (hexavalent chrome) compounds due to the performance enhancement that it gives the coating. Non-chrome systems do exist for liquid coatings going over aluminum substrates, but their performance can be somewhat diminished especially in coastal environments. Also,

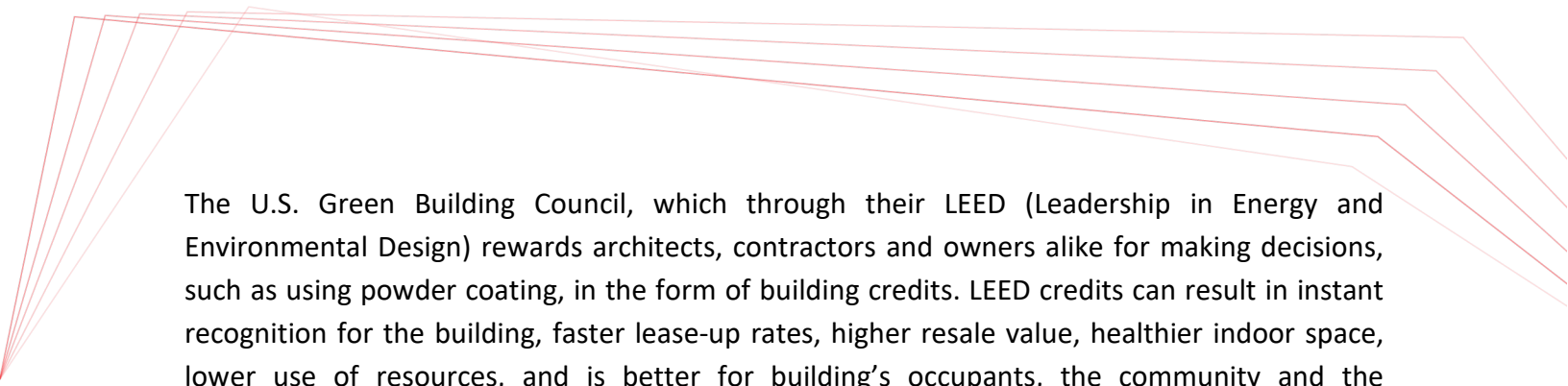
applicators that coat steel (coil coaters) in addition to aluminum, typically use chromate systems because the non-chrome pretreatment designed for architectural aluminum does not work on steel. Powder coating applicators (and manufacturers) have embraced the development of non-chrome systems and have had great success in implementation. This has proven to be a major advantage for powder coatings in the high-performance architectural market.

For the applicator, liquid coatings also require the use of solvents for cleaning equipment and coating environments. These solvents pose certain health risks for personnel that have to manage these processes. The largest impact that solvent has on the environment, however, is during the baking process. Kynar 500®, for example, is 43% to 51% solvent by weight which means that roughly half of the weight of coating processed evaporates during the curing process, which ranges from 450° F to 475°F. Many coaters do use thermal oxidizers to lessen the effect of the harmful compounds getting into the atmosphere, but there is an impact on natural resources as this equipment consumes an enormous amount of natural gas and electricity to operate. Powder coatings do not contain or require the use of solvent for function or for cleaning. Cleaning is mostly done by the application equipment which keeps the over-sprayed powder contained and the residue is easily vacuumed or wiped up with dry rags.

Powder coating consumes less energy throughout the entire process. Liquid coatings require higher air flow to be sprayed and higher air flow for the operation of the booth as compared to powder coating. The liquid overspray cannot be recycled, as is the case for powder coating, greatly reducing the utilization of the coating material, which in turn, consumes more energy. The recirculation aspect of liquid coating curing ovens requires 5-9 more turns of air in order to deal with solvent emissions. This requires that more natural gas be used to maintain the heat required for the process. Powder coating can typically be applied more quickly which increases the area coated per unit time ratio, reducing costs.

The performance of liquid coatings compared to powder coatings shows them to be quite similar in many ways. However, it should be noted that liquid coatings, specifically PVDF-containing coatings like Kynar 500®, are thermoplastic in contrast to powder coatings, which are commonly thermosetting, and as such, have softer films which can be more susceptible to scratches and abrasion. Pencil hardness testing shows liquid coatings to be in the range of F to H, while powder can easily attain 3H and even 4H hardness. (refer to Appendix A)

Another consideration that is important to note is that projects that involve the “cradle to cradle” design feature are compromised when using liquid coatings over chromate pretreatment. The chromium content prevents these materials from being landfilled at the end of their service life and thus they must be treated as hazardous waste, typically at the owner’s expense.



The U.S. Green Building Council, which through their LEED (Leadership in Energy and Environmental Design) rewards architects, contractors and owners alike for making decisions, such as using powder coating, in the form of building credits. LEED credits can result in instant recognition for the building, faster lease-up rates, higher resale value, healthier indoor space, lower use of resources, and is better for building's occupants, the community and the environment.

The global powder coatings market size, worldwide, is currently about \$13 billion and is expected to surpass \$17 billion by 2025. Industry experts attribute this to not only the minimal environmental impact, but also to the value-added proposition that powder coatings offer, new technology advances, faster applicability, and excellent performance characteristics. Architectural applications present some of the best opportunities for powder coating growth due to the hazardous ingredients involved with liquid coating.

Today's architectural market is more dynamic than ever. Creative designs, physics-defying engineering, ascending closer to the sky, advancing nearer to the sea, pushing the edge of the envelope even further - call for the best that technology has to offer. All of this must exist in a world where each and every one of us must step up our sustainability game and make a more significant contribution to our future and to the future of those who succeed us. It is our actions that pay this forward. Actions that result from innovation, ingenuity, hard work, and pragmatism; these actions advance the art, making it better in every way possible.

Appendix A Coating Comparison Data

AAMA 2604 Finishes Comparison

50% PVDF (Polyvinylidene Fluoride) Liquid Coating

vs.

Powder Coating (Super-Durable Polyester)

The tables below show the performance characteristics of both 50% PVDF (Kynar resin) and powder coatings based upon super-durable polyesters. The main difference of these two coatings, besides their state of phase, is that the liquid coating is a thermoplastic and the powder coating is a thermoset. Thermoplastics do not undergo a permanent, one-way, infusible reaction as do thermosets. By virtue of this, thermosets are typically much harder and more scratch resistant, resulting in a tougher film versus their thermoplastic counterparts. Both varieties display excellent weathering and corrosion resistance. PVDF (50% Kynar resin) liquid coatings are more recognized by their commercial names such as Acrodize HardCoat™, AcroFlur™, etc. Gordon's AcroGuard®, AcroGuard UVX® and AAMA 2604 powder coatings are based on Super-Polyester technology.

Properties	Test Method	50% PVDF Liquid Coating	Powder Coating
Textures	N/A	No	Yes
Gloss Range (at 60°)	ASTM D523	5-25	5-90
Color Range ¹	N/A	Wide range of solids & metallics	Wide range of solids & metallics
Smoothness (PCI Scale) ²	PCI Tech Brief #20	5-8	5-8

Aluminum Substrate	Test Method	50% PVDF Liquid Coating	Powder Coating
Pretreatment, typ. ³	N/A	Tri/Hex Valent Chrome	Chrome-free dry-in-place
Impact Resistance (deformation)	ASTM D2794	2.5 mm*	3.0 mm*
Pencil Hardness ⁴	ASTM D3363	H*	3H*
Taber Abrasion (Wear Index) ⁵	ASTM D4060	140*	100*
Adhesion	ASTM D3359	5B	5B
100 Double Rubs MEK	PCI Method #8	PASS*	PASS*
Mandrel Bend	ASTM D522	¼" *	¼" *
Film Thickness	ASTM D7091	1.2 min*	2.0 min*

Aluminum Substrate	Test Method	50% PVDF Liquid Coating	Powder Coating
South Florida UV Resistance	Per AAMA 2604-17a	Up to 10 years, Gloss retention: 30%+, Color Retention: ΔE <5.0	Up to 10 years, Gloss retention: 30%+, Color Retention: ΔE <5.0
Salt Spray Resistance (ASTM B117)	ASTM B117	3000 hrs.*	3000 hrs.*
Humidity Resistance	ASTM D2247	4000 hrs.*	4000 hrs.*

Chemical Reagent ⁶	Rating	50/% PVDF Liquid Coating	Powder Coating
Sulfuric Acid 40% ⁶	1-5	1*	5*
Nitric Acid 20% ⁶	1-5	1*	5*
Phosphoric Acid 85% ⁶	1-5	1*	5*
Hydrochloric Acid 37% ⁶	1-5	1*	5*
Acetic Acid 40% ⁶	1-5	1*	5*
Sodium Hydroxide 40%	1-5	5*	5*
Ammonia Sol. 29%	1-5	5*	5*
Ethanol 95%	1-5	5*	5*
Methanol	1-5	5*	5*
Diesel	1-5	5*	5*
Formaldehyde	1-5	5*	5*
Vegetable Oil	1-5	5*	5*

Rating: 5=Unaffected 4=Color/Gloss change 3=Softens; recovers 2=Softens; no recovery 1=Blistered

* Results based on actual tests performed by an independent lab

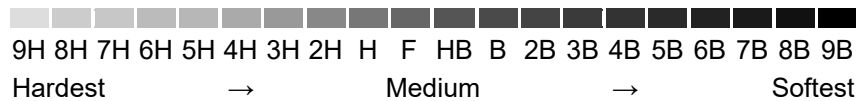
Footnote:

¹ Color ranges can be limited by high chromaticity which could facilitate the need for a clear top coat.

² PCI smoothness is directed by a set of 10 standard panels that vary in smoothness; 1 being the least smooth and 10 which represents nearly perfect smoothness.

³ Pretreatment chemicals for PVDF coatings typically contains either trivalent or hexavalent chrome. Chrome is a heavy metal and extremely hazardous. Gordon powder coatings are applied over chrome-free pretreated substrates and exhibit excellent performance.

⁴ Pencil Hardness Scale



⁵ Taber Wear Index - Indicates rate of wear and is calculated by measuring the loss in weight (in milligrams) per thousand cycles of abrasion. The lower the wear index, the better the abrasion resistance.

⁶ Coating was exposed to 5 drops of each reagent applied to a cotton ball and placed under a watch glass for 150 hours. At the end of the test the coating was rinsed with water and evaluated. Acrodize HardCoat was found to be inherently weak against acids.

AAMA 2605 Finishes Comparison

70% PVDF (Polyvinylidene Fluoride) Liquid Coating vs. FEVE (Fluoroethylene Vinyl Ether) Powder Coating

The tables below show the performance characteristics of both 70% PVDF (Kynar resin) and powder coatings based upon FEVE (Fluoroethylene Vinyl Ether). The main difference of these two coatings, besides their state of phase, is that the liquid coating is a thermoplastic and the powder coating is a thermoset. Thermoplastics do not undergo a permanent, one-way, infusible reaction as do thermosets. By virtue of this, thermosets are typically much harder and more scratch resistant, resulting in a tougher film versus their thermoplastic counterparts. Both varieties display excellent weathering and corrosion resistance. PVDF (70% Kynar resin) liquid coatings are more recognized by their commercial names such as Kynar 500™, Fluoropon®, Duranar®, etc. Gordon's AAMA 2605 powder coatings are based on FEVE technology which is an ultra-high-performance fluoropolymer molecule that is chemically crosslinked, surpassing the requirements of AAMA 2605.

Properties	Test Method	70% PVDF Liquid Coating	FEVE Powder Coating
Textures		No	Yes
Gloss Range (at 60°)	ASTM D523	20-35	20-65
Color Range ¹		Wide range of solids & metallics	Wide range of solids & metallics
Smoothness (PCI Scale) ²	PCI Tech Brief #20	6-8	6-8

Aluminum Substrate	Test Method	70% PVDF Liquid Coating	FEVE Powder Coating
Pretreatment, typ. ³		Tri/Hex Valent Chrome	Chrome-free dry-in-place
Impact Resistance (deformation)	ASTM D2794	3.0 mm*	3.0 mm*
Pencil Hardness ⁴	ASTM D3363	F*	4H*
Taber Abrasion (Wear Index) ⁵	ASTM D4060	140*	100*
Adhesion	ASTM D3359	5B	5B
100 Double Rubs MEK	PCI Method #8	PASS*	PASS*
Mandrel Bend	ASTM D522	¼" *	¼" *
Film Thickness (mils)	ASTM D7091	1.2 min.*	2.0 min*

Aluminum Substrate	Test Method	70% PVDF Liquid Coating	FEVE Powder Coating
South Florida UV Resistance	Per AAMA 2605-17a	20 years, Gloss retention: 50%+, Color Retention: ΔE <5.0	20 years, Gloss retention: 50%+, Color Retention: ΔE <5.0
Salt Spray Resistance	ASTM B117	4000 hrs.*	4000 hrs.*
Cyclic Corrosion	ASTM G-85	2000 hrs.*	2000 hrs.*
Humidity Resistance	ASTM D2247	4000 hrs.*	4000 hrs.*

Chemical Reagent ⁶	Rating	70/0% PVDF Liquid Coating	FEVE Powder Coating
Sulfuric Acid 40% ⁶	1-5	5*	5*
Nitric Acid 20% ⁶	1-5	5*	5*
Phosphoric Acid 85% ⁶	1-5	5*	5*
Hydrochloric Acid 37% ⁶	1-5	5*	5*
Acetic Acid 40% ⁶	1-5	5*	5*
Sodium Hydroxide 40%	1-5	5*	5*
Ammonia Sol. 29%	1-5	5*	5*
Ethanol 95%	1-5	5*	5*
Methanol	1-5	5*	5*
Diesel	1-5	5*	5*
Formaldehyde	1-5	5*	5*
Vegetable Oil	1-5	5*	5*
Rating: 5=Unaffected 4=Color/Gloss change 3=Softens; recovers 2=Softens; no recovery 1=Blistered			

* Results based on actual tests performed by an independent lab

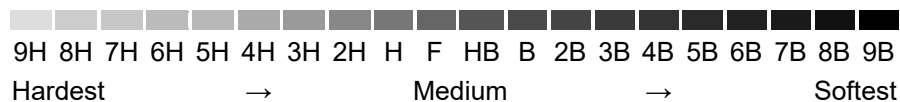
Footnote:

¹ Color ranges can be limited by high chromaticity which could facilitate the need for a clear topcoat.

² PCI smoothness is directed by a set of 10 standard panels that vary in smoothness; 1 being the least smooth and 10 which represents nearly perfect smoothness.

³ Pretreatment chemicals for PVDF coatings typically contains either trivalent or hexavalent chrome. Chrome is a heavy metal and extremely hazardous. Gordon powder coatings are applied over chrome-free pretreated substrates and exhibit excellent performance.

⁴ Pencil Hardness Scale



⁵ Taber Wear Index - Indicates rate of wear and is calculated by measuring the loss in weight (in milligrams) per thousand cycles of abrasion. The lower the wear index, the better the abrasion resistance.

⁶ Coating was exposed to 5 drops of each reagent applied to a cotton ball and placed under a watch glass for 150 hours. At the end of the test the coating was rinsed with water and evaluated.

Appendix B AAMA 2604 and AAMA 2605 Tests

Test	Reference	Performance	
		AAMA 2604	AAMA 2605
Color Uniformity	ASTM D2244	2 ΔE units	2 ΔE units
Specular Gloss (60°)	ASTM D523	± 5 of mfg. spec.	± 5 of mfg. spec.
Dry Film Hardness	ASTM D3363	F	F
Film Adhesion (Sequential)		4B Minimum	4B Minimum
1. Dry adhesion	ASTM D3359	These tests are run in sequential order and the result after all three tests are completed should be a minimum of 4B. (based on Method B)	
2. Boiling Water Adhesion	AAMA 2604/2605 8.4.1.2		
3. Wet Adhesion	AAMA 2604/2605 8.4.1.3		
Impact Resistance	AAMA 2604/2605 8.5.1	No removal of film	No removal of film
Abrasion Resistance	ASTM D968	20 liters/mil	40 liters/mil
Chemical Resistance	AAMA 2604/2605 section		
Muriatic Acid	8.7.1.1	No visual change	No visual change
Mortar resistance	8.7.2.1	No visual change or loss of adhesion	No visual change or loss of adhesion
Nitric Acid	8.7.3.1	< 5ΔE units of color change	< 5ΔE units of color change
Detergent Resistance	8.7.4.1	No blistering, loss of adhesion or significant visual change	No blistering, loss of adhesion or significant visual change
Window cleaner Resistance	8.7.5.1	No blistering, loss of adhesion or significant visual change	No blistering, loss of adhesion or significant visual change

Test	Reference	Performance	
		AAMA 2604	AAMA 2605
Corrosion Resistance			
Humidity resistance	ASTM D 2247	3,000 hours	4,000 hours
Salt Spray Resistance	ASTM B117	3,000 hours	Not applicable
Cyclic corrosion Resistance		Not applicable	2,000 hours
Weathering (South Florida exposure)			
Color Retention	ASTM D2244	≤ 5ΔE units	≤ 5ΔE units
Chalk Resistance	ASTM D4214	≥ 8 colors, ≥ 6 whites	≥ 8 colors, ≥ 6 whites
Gloss Retention	ASTM D523	30%	50%
Resistance to Erosion	ASTM B244	< 10% Loss of film	< 10% Loss of film

American Architectural Manufacturers Association (AAMA)

- AAMA 800-10 Voluntary Specification and Test Method for Sealants
- AAMA 2604-17a - Voluntary Specification, Performance Requirements and Test Procedures for High Performance Organic Coatings on Aluminum Extrusions and Panels (with Coil Coating Appendix)
- AAMA 2605-17a - Voluntary Specification, Performance Requirements and Test Procedures for Superior Performance Organic Coatings on Aluminum Extrusions and Panels (with Coil Coating Appendix)
- AAMA 2604 and AAMA 2605 shared test methods
 - 8.4.1.2 Boiling Water
 - 8.4.1.3 Wet Adhesion
 - 8.5.1 Impact Resistance
 - 8.7.1.1 Muriatic Acid Resistance (15-minute spot test)
 - 8.7.2.1 Mortar Resistance (24-hour Pat test)
 - 8.7.3.1 Nitric Acid Resistance
 - 8.7.4.1 Detergent Resistance
 - 8.7.5.1 Window Cleaner Resistance
- AAMA AG-12 AAMA Glossary (ref. 2605)
- AAMA AG-13 AAMA Glossary (ref. 2604)

American Society for Testing and Materials (ASTM International)

- ASTM B117 Standard Practice for Operating Salt Spray (Fog) Apparatus
- ASTM B244-09 Standard Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Non-conductive Coatings on Non-magnetic Basis Metals with Eddy-Current Instruments
- ASTM C207-06 Standard Specification for Hydrated Lime for Masonry Purposes
- ASTM D523-08 Standard Test Method for Specular Gloss
- ASTM D714-02 Standard Test Method for Evaluating Degree of Blistering of Paints
- ASTM D968-05(2010) Standard Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
- ASTM D1654-08 Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments
- ASTM D2244-11 Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

- ASTM D2247-11 Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity
- ASTM D2248-01a (2007) Standard Practice for Detergent Resistance of Organic Finishes
- ASTM D2369-10 (2015) Standard Test Method for Volatile Content of Coatings
- ASTM D2454-18 Standard Practice for Determining the Effect of Overbaking on Organic Coatings
- ASTM D2803-09 Standard Guide for Testing Filaform Corrosion Resistance of Organic Coatings on Metal
- ASTM D3359-17 Standard Test Methods for Rating Adhesion by Tape Test
- ASTM D3363-05(2011) e2 Standard Test Method for Film Hardness by Pencil Test
- ASTM D4214-07 Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films
- ASTM D4217 Test Method for Gel-Time of Thermosetting Powder Coatings
- ASTM D4242 Test Method for Inclined Plate Flow for Thermosetting Powder Coatings
- ASTM D4585-07 Standard Practice for Testing Water Resistance of Coatings Using Controlled Condensation
- ASTM D6441-05 Standard Test Methods for Measuring the Hiding Power of Powder Coatings
- ASTM D7091-12 Standard Practice for Non-Destructive Measurement of Dry Film Thickness of Non-Magnetic Coatings Applied to Ferrous Metals and Non-Magnetic, Non-Conductive Coatings applied to Non-Ferrous Metals
- ASTM G7/G7M-13 Standard Practice for Atmospheric Environmental Exposure Testing of Non-Metallic Materials
- ASTM G85-11 Standard Practice for Modified Salt Spray (Fog) Testing

British, European and International Standards (BS EN ISO)

- BS EN ISO 12944-2(1) Paints and varnishes — Corrosion protection of steel structures by protective paint systems (Part 2: Classification of environments)

AAMA – Acronym for American Architectural Manufacturers Association. AAMA is the recognized creator of performance specifications, certifications, and educational materials for the fenestration industry. In the scope of high-performance, aluminum extrusions and panels, their 2604 and 2605 specifications are most recognized in North America.

Adhesion – State in which two surfaces are held together by interfacial forces which may consist of valence forces or interlocking action, or both.

Alkaline (wash) – In non-chrome pretreatment, parts are typically washed in a concentrated alkaline solution, which is highly basic, with a pH > 13.0, typically. This step is usually the initial stage in a multi-stage cleaner/pretreatment system and is always followed by a thorough rinse.

Alloy – A homogenous mixture or solid solution of two or more metals, the atoms of one replacing or occupying the interstitial positions between the atoms of the other. Aluminum used in architecture is frequently alloyed with other metals to optimize performance.

ASTM – Acronym for and formerly known as *American Society and Testing for Materials*. ASTM is an international body which documents, governs, and coordinates test methods for all types of materials and processes. These test methods, as well as, combinations or derivations are frequently used in the quantitative analysis of coatings and are frequently cited throughout this paper.

Bonding – Bonding is a process used in powder coating manufacture to literally bond or attach thermosetting powder particles to dissimilar particles, such as metallic pigments or micas to facilitate consistent deposition of the mixture through the powder coating application process. This bond is created by added radiant heat or frictional heat or both such that the powder particle is softened to the point that a dissimilar particle can be attached to it and then subsequently cooled thus fusing the particles together.

Chromate – A compound (salt) whereby Chromium in the 6+ oxidation state (hexavalent chrome) is compounded with oxygen. Chromate can be interconvertible with di-chromate in aqueous solutions and is a strong oxidizer. In coatings, it is used as a pretreatment to aluminum and steel to protect against corrosion.

Conversion Coating – A treatment, either chemical or electrochemical, of the metal surface to convert it to another chemical form which provides an insulating barrier of exceedingly low solubility between the metal and its environment, while remaining an integral part of the metallic substrate. This provides an enhanced bonding site for the top coating to be applied, resisting the forces in nature that promote corrosion and disbondment.

Corrosion – The deterioration of metal by chemical or electrochemical reaction resulting from exposure to weathering, moisture, chemicals, or other agents in the environment in which it is placed. (also see filiform corrosion)

Crosslinking – Applied to polymer molecules, the setting up of chemical links between the molecular chains to form a three-dimensional or network polymer generally by covalent bonding. In coatings, this typically happens between resin molecules and curative molecules to build much larger molecules that can be stable in a solid-state.

Curative (hardener) – resinous substance or additive that promotes the curing (or hardening) of a coating, plastic, adhesive or resin system. It typically has bonding sites which are shared with atoms of resins to facilitate polymerization.

Cyclic Corrosion Testing (CCT) – Corrosion test has evolved in recent years, as a way of accelerating real-world corrosion failures, under laboratory-controlled conditions. As the name implies, the test comprises different climates which are cycled automatically so the samples under test undergo the same sort of changing environment that would be encountered in the natural world. This test is exclusive to AAMA 2605.

Etching – A process using acid or perhaps mechanical means, particularly on aluminum in this context, whereby the surface is roughened as to promote adhesion of subsequent layers.

Extruder (powder coating) – A machine capable of melt-mixing resinous and inert ingredients into a homogenous, molten paste or extrudate. Extrudate is subsequently cooled and run through a mill to create a powder coating. Quality of extrusion is imperative to a high-performance powder coating.

FEVE – Acronym for Fluoroethylene Vinyl Ether, which is the backbone of AAMA 2605 capable powder coatings. This technology emerged commercially in the early 1980s and saw wide -spread application by the mid-1990s. Combined with poly di-isocyanate, double carbon covalent bonds are formed which are extremely robust and stand up well to ultraviolet rays from the sun.

Filaform Corrosion – A type of corrosion that occurs under coatings on metal substrates characterized by a definite thread-like structure and directional growth. ASTM D2803 provides a method for determining the susceptibility of organic coated metal substrates to formation of filaform corrosion.

Fluidize – The process of passing air through a powder coating to cause it to behave as a fluid. This can be done with a vessel that contains a porous plate at the bottom and passing a particular volume and pressure of air evenly across the porous surface. The powder mixes with the air and is easily managed for the purpose of spraying.

Fluoropolymer (fluorocarbon) – A fluoropolymer is a compound that contains Fluorine usually in combination with Carbon and Hydrogen. This chemical classification encompasses all high-performance organic resins used for architectural coatings. FEVE and PVDF would be a part of this group of compounds.

Gloss – A subjective term that refers to the relative amount and nature of mirror-like (specular) reflectance. Gloss can be measured quantitatively with a meter relative to polished plate glass which is a gloss of 100. This working standard assists in the measurement of the gloss of coatings. The angle of measurement (typically 60°) is critical in establishing a gloss level. Gloss is used to measure the

degradation of coatings exposed to weathering and UV radiation. Gloss also plays an important role in the aesthetic quality of a coating relative to its application.

Green Building Council (US) – The United States Green Building Council is an organization that rewards contractors, architects, and owners on their design and material choices. This can be based on a number of factors such as conservation of natural resources, impact on the environment, safety for the building's occupants, and sustainability.

HAP – Acronym for Hazardous Air Pollutant. The EPA issues limits on the amount of hazardous air pollutants that any single entity can release. Solvents, like those used in liquid paint, can greatly impact air quality and in-turn, users of these materials are urged to reduce their emissions and look for cleaner methods, such as powder coating.

Hexavalent Chrome – *see Chromate.*

Kynar 500® – Tradename of the liquid architectural coating that contains 70% PVDF resin. Kynar 500® is a thermoplastic liquid paint that is used over a primer coat and chromate-prepared metal substrate. These coatings have been in use for decades and have facilitated the need for cleaner coating alternatives that are compliant with AAMA specifications.

LEED – Acronym for Leadership in Energy and Environmental Design. These are credits awarded to architects, contractors, and owners which are based on choices of materials and designs that are environmentally sound and preserve resources. These credits add intrinsic value to building projects in the form of resale value, safety, comfort, building recognition, and faster lease-up rates.

Mica – Also known as aluminum potassium silicate, mica crystals are most commonly derived from muscovite which permits the splitting into thin, flaky pigment particles that can undergo many types of treatments and colorations. Typically, mica is used as a durable special-effect pigment that can simulate metallic materials.

Mixed metal oxide – pigment that is created with metal ions and oxygen, silicon, phosphorous or sulfur, through a process known as calcination that creates a pigment with a crystal lattice structure that is highly durable and resistant to ultraviolet radiation. These pigments are commonly used in AAMA 2605 coating due to their resistance to weathering.

Molecular weight – The sum of the atomic weights of all the atoms in a molecule.

Pigment – A finely ground, natural or synthetic, organic or inorganic, insoluble particle, that when dispersed in a coating, may provide, in addition to color, many of the coating's essential properties.

Polymer – A substance, the molecules of which consist of one or more structural units (monomers) repeated any number of times. Coatings, more specifically, can be categorized as copolymers since the polymer chain consists of more than one type of structural unit.

PVDF – Abbreviation for Polyvinylidene difluoride. PVDF is the polymeric structure that serves as the backbone for the thermoplastic architectural coating known as Kynar 500®. It was derived from a compound known as polyvinyl fluoride and became commercially available on a large scale in the mid-1960s.

Resin – General term applied to a wide variety of (more or less) transparent, organic, and fusible products, which may be natural or synthetic. High molecular weight synthetic resins are generally referred to as polymers. Moreover, resins are the base material for coatings and plastics. Oils such as linseed or Tung oil are processed from plant materials and served as the basis for coatings for centuries.

Reverse Osmosis – A purification process that uses a partially permeable membrane to remove ions, unwanted molecules, and larger particles from water. By applying pressure to overcome osmotic pressure, the solute will remain on the pressurized side of the membrane and the solvent (water) is allowed to pass through. In pretreatment systems, RO water is used for making chemical baths as well as rinsing between stages. The RO water, typically < 3 ppm contaminate level, leaves a residue free surface that promotes good paint adhesion.

Super (Durable)-polyester – Refers to a class of polyester resins for powder coatings, which have a higher content of isophthalic acid which create highly branched polymer structures having increased resiliency against ultraviolet radiation exposure. These resins are commonly used in AAMA 2604 compliant powder coating finishes.

Sustainability - The process of people maintaining change in a stable, balanced environment, in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. In the context of this paper, coating processes have been shown to improve sustainability as the move to safer, more efficient processes. This concept is perpetuated to subsequent tiers of manufacturing as the coated parts, too, are of a more sustainable form.

Synthetic resin – A resin that is synthesized from petroleum products, as well as, various acids and alcohols. These were derived as the need for supplementing natural resins, which were in short supply, became necessary. Much larger molecules could be created which gave way to better performing coating materials. Synthetic resins are used for most coatings and plastics produced today.

Thermal oxidizer – Thermal oxidizers are used to destroy HAPs and VOCs from solvents contained in industrial air streams. These pollutants are generally hydrocarbon based and when destroyed via thermal combustion they are chemically oxidized to form CO₂ and H₂O. Most direct-fired thermal oxidizers operate at temperature levels between 1,800 °F and 2,190 °F with air flow rates of 500 cfm to 50,000 cfm.

Thermoplastic – A typically polymeric substance that is capable of being softened by heat and hardened by cooling.

Thermoset – A material which will undergo or has undergone a chemical reaction by the action of heat, catalysts, ultraviolet light, etc., leading to a relatively infusible state.

Ultraviolet Radiation (UV)– The area of the electromagnetic spectrum between 10 nm and 400 nm (just below visible light). The area of concern being around 340 nm which represents the UV radiation in sunlight. This radiation puts vibrational stress on covalent bonds which causes degradation, particularly in coatings. Weaker bonds are subdued by this energy and subsequently cause their molecules to fragment, resulting in different types of failure, i.e. chalking, fading, and erosion.

VOC – Abbreviation for volatile organic compound. VOCs are contained in most liquid paints, especially those associated with high-performance architectural applications. The manufacturer is required to list VOC content on the container in the unit of measure depicted as pounds per gallon. Applicators of these types of liquid paints are required to maintain air permits and are limited on the VOC content that is released annually. These compounds often contain hazardous air pollutants (HAPs) and contribute to the ongoing problem of air pollution.

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