

A Case Study in Progress: Replacing an Incumbent Coating Technology

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ABSTRACT

Supporting the business decision to challenge an incumbent coating technology with physical vapor deposition (PVD), the technologist faces a plethora of changes. A new vacuum-deposited coating replaces electroplating for automotive exterior plastic trim and presents a classic example of managing technological change. The requirements across the industrial network, from molder to end user, are described. While the new PVD coating can match incumbent gloss and satin appearances, success is fostered by focusing on a specific product definition. Although the new PVD coating excels in durability and exposure testing, harmonizing the test methods and criteria across original equipment manufacturers (OEMs) would accelerate market entry. Addressing heat management intrinsic to PVD processes, a process with sufficient thickness and hardness to meet both durability and cost targets has been developed. A means to change the mindset around cleaning this new coating, indeed PVD coatings on plastic in general, is addressed.

INTRODUCTION

This paper focuses on the technological leadership role in new product introduction. Hopefully, the development team takes advantage of Stage-Gate® processes, pioneered by Robert Cooper [1]. Many of the ideas presented here parallel the concepts in those stages. Organizations adhere to formal product birth and growth stages with varying levels of rigor. Speed to market is almost always a driving factor, so formality is often dropped. Always keep in mind that, as strong, wise and well proven as phased, gated approaches to development are, they exist to serve the business, not the other way around. Should an organization attend loosely to these precepts, the more one does oneself, the more likely one's success. After business, commercial, and technology considerations lead to organizational commitment to challenge an existing technology, the obstacles the technologist faces displacing an incumbent technology differ from those

entering a newly forming market. The creator of a new market contributes to forming new expectations but may have to develop entire new supply chains [2]. The technology challenger may benefit from many existing pathways but must go up against established expectations. Most innovations lie somewhere between these extremes. The sooner the goal is identified, the tech leader can marshal and deploy resources strategically.

In the case at hand, Vergason Technology, Inc. (VTI), has decided to challenge the incumbent electroplating process for producing a chrome appearance on plastic automotive exterior trim parts. Almost all of the shiny metal surfaces on modern automobiles are electroplated chrome plating on plastic (POP). See Figure 1. The \$2B–\$4B global electroplating industry serves not only the automotive market but also the sanitary fixture and white goods markets with shiny, durable surfaces on these plastics. High-gloss surfaces are not the only types produced with electroplating processes. There is a significant industry in plating bath chemical additives that produce various levels of satin or matte finishes, as well as different levels of overall reflectivity.



Figure 1. Examples of plating-on-plastic (POP) metallic finishes on the side of an automobile.

PRODUCT AND PROCESS DEFINITION

Good business begins and ends with the customer. In this case, that is the automobile original equipment manufacturer (OEM). Clear product definition promotes team success. Definition includes the material system, product attributes, and selected processes. VTI targets plating-grade ABS/PC blends. A flowable liquid provides a smooth surface. The new product's durability and appearance must meet or exceed those of the incumbent. In particular, appearance must match the incumbent with no perceptible difference. Although a wide variety of finishes and reflectivity levels have been developed over decades for plating-on-plastic (POP), a focus on a high-reflection, high-gloss surface is chosen (see Figure 2). Even though focus must be maintained, business reality dictates that adjacent markets be addressed in real time. In this case, the sanitary and white goods market requirements are different enough that different products must be acknowledged. While actively working on these other finishes and markets in parallel, conscious distinction aids focus. Market acceptance of the high-gloss automotive product will allow time and resources for developing other finishes and markets.

SuperChrome™ 0.3-1.15 μm	Chromium 0.2-0.3 μm
UV/Thermal Paint 20-40 μm	Nickel and Copper 20-50 μm
Plastic Substrate	Plastic Substrate
SuperChrome™ PVD	Typical electroplated chrome incumbent

Figure 2. Comparison of SuperChrome™, PVD to electroplated chrome on plastic (incumbent technology). In the SuperChrome™ process, a paint layer replaces the nickel and copper metallic electroplated layers. Both coatings have similar layers of exposed chromium.

The business must identify the key drivers for the planned change. In this case, environmental safety, manufacturing cost, and product weight are key drivers. Hexavalent chrome has been an essential material in this plating process. Unfortunately, hexavalent chrome is a serious carcinogen. It is so bad that the European registration, evaluation, authorization and restriction of chemicals (REACH) initiative is calling for the process to be eliminated by September of 2017. While no similar ban has legal status in the United States, federal restrictions on control and monitoring are not insignificant [3]. For the auto industry, cost reductions of pennies per part are significant. The auto industry is always conscious of weight reduction. In this application, since the coating being challenged is a thick, dense metal, there is a weight advantage to a coating produced by physical vapor deposition (PVD).

Near the beginning, the technologist needs to assess the suitability of the existing tools and the process know-how in-house for the core processing needs. In this case, the existing resources are well matched to the challenge. The author's organization has experience supplying sputter coating systems along with tooling for spray painting and UV and thermal curing. Since a need for strong mechanical properties is anticipated, ultraviolet (UV) and dual UV/thermal curing processes are selected.

SUPPLY CHAIN

A challenger should assess the industrial network in which the innovation must thrive. This includes the supply chain (see Figure 3), performance requirements, testing standards, and end user perceptions.

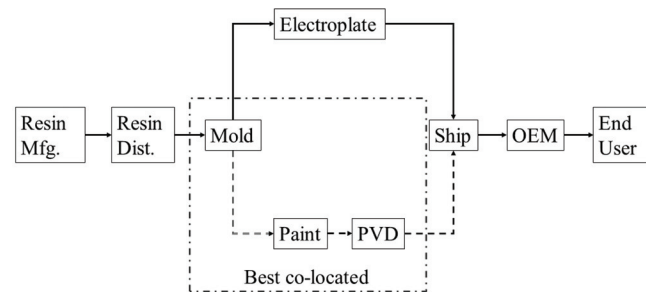


Figure 3. Incumbent (solid arrows) and new “challenger” supply chains (dashed arrows). In the case of the challenger, the molding, painting, and PVD process are best co-located.

POLYMER SUBSTRATES

Everyone in coatings has struggled with substrate properties, surface quality, and cleanliness. One difference between a totally new product and challenging an incumbent arises when selecting substrate. While both approaches require filtering candidates suited to the application, the challenger is also subject to the characteristics of the incumbent. Over decades, “plating-grade” ABS and ABS/PC blends have been developed to aid the electroplating process. Some of the butadiene in the ABS is chemically etched to provide roughness suited to electroplate adhesion. PVD coatings have no such limitation. They have shown excellent adhesion to a wide variety of plastics. However, ABS heat tolerance can be a problem for PVD, while there is no significant heat in the electroplating arena. The incumbent materials have certain set expectations. OEMs have invested in accelerated and long-term materials testing. While other plastics may be better for automotive parts in PVD, the challenger must begin by demonstrating excellent performance on the materials that are currently accepted in the industry.

Once PVD is widely accepted, other plastics might be demonstrated as superior and might be gradually phased in.

MOLDER

Learn to intervene early when the innovation puts new demands on the supply chain. Engage with all those involved. Downstream of the resin supplier, the molder determines not only the shape but also the surface finish and the residual stress profile of the part. Substrate heating is a key difference between electroplating and PVD. Residual stresses can be locked into a part during the molding process, depending on factors including part geometry, placement of mold gates, injection pressure, and mold temperature profile. If the part is kept cool after molding, these stresses are often not observed. Stress relaxation in molded parts can be triggered if the combination of residual stress and thermal history is high enough and material thickness and softening point is low enough. In the present case, desired results can be accomplished by working with the molder during mold design to avoid problems and with the mold operator to control temperature and pressure within acceptable ranges. The PVD chamber and process have been crafted to tolerate ABS/PC blends well.

PAINT

In most cases, the surface finish from molding is not sufficiently specular for high-gloss parts. The major shift in the supply chain is introduced here. The incumbent relies on tens of microns of metal to provide a hard foundation for chromium and to control the surface texture. The SuperChrome™ coating process relies on the flow characteristics of paint to produce the desired smoothness and paint chemistry to optimize hardness. Paint, followed by opaque PVD aluminum, finished with a clear paint top coat, has a long history in automotive lighting. Automotive OEMs are familiar with metalizers who own paint lines and are familiar with their pricing, delivery, and quality issues. SuperChrome™ requires a longer deposition time than aluminum reflectors, and the top paint layer is completely eliminated. Changing the supply chain for chrome parts is significant, and this level of supply chain familiarity is a significant advantage.

The expectations for mechanical performance of POP are much higher than for common paints. Paint development is outside the author's organization's expertise. In this case, different curing processes need to be considered. The leading candidates for three-dimensional parts are thermal, UV, and combinations of the two. The existing installed base of

thermal is significantly larger than UV. UV has advantages; it minimizes process time and equipment footprint. For good adhesion, the paint formulation needs to be matched to the resin class. The most effective approach to displacing the incumbent is to minimize unnecessary disruptions to the existing supply chain. A well-respected organization creates better supply chain trust. The author's organization's partnership with Mankiewicz Coatings (Charleston, SC) has resulted in new combinations of paint formulations and curing conditions optimized for SuperChrome™. There are both exclusively UV and IR/UV dual-cure processes available. The paint formulation flows well to provide leveling, has excellent adhesion to ABS and ABS/PC blends, and has hardness suited to the full stack. It passes 72-hour, 95°C/95 %RH hydrolysis as well as all required environmental tests.

PVD

Attempts have been made over the years to replace electroplated chrome on plastic with PVD coatings. As far back as 1975, John Thornton [4] was sputtering Cr onto ABS. There were issues with cost, cracking, and durability. VTI has developed a reactive sputtering process in conjunction with metallic chromium that fills all requirements [5].

OEM

As soon as prototypes are available, refine priorities with the OEMs. Technical performance, price, and speed to market are always important, but it is essential to know early how the OEM ranks these. Keep three dimensions in mind while determining true technical requirements. Formal specifications are only one dimension. Another dimension is the challenger's new, attractive attributes that may factor in an acceptance decision. Perhaps the most influential dimension can be the unspoken, informal perceptions of the incumbent that are often not communicated until the OEM has prototypes in hand. Price will always be a consideration. The incumbent will have set a benchmark that benefits from years of work to drive down costs.

Both technical requirements and price have some temporal flexibility. There is usually a tacit expectation that price will decline over time. At this point in product introduction, the organization is confident that manufacturing cost will not exceed that of electroplating. Lower costs may be possible. If a supplier cannot meet all expectations immediately, an OEM may proceed with expectations of future improvement. This flexibility does not necessarily exist for speed to market; first to market is a one-time event.

Table 1. Approximate weight difference between electroplating on plastic and SuperChrome™.

Electroplate				SuperChrome™			
Material	Thickness (microns)	Density (g/cm ³)	Weight (g/cm ²)	Material	Thickness (microns)	Density (g/cm ³)	Weight (g/cm ²)
Cr	0.3	7.14	0.000214	Cr	0.3	7.14	0.000214
Ni	27	8.908	0.02405	Paint	35	1.2	0.0042
Cu	13	8.96	0.01165				
PC/ABS	2000	1.13	0.226	PC/ABS	2000	1.13	0.226
Total			0.261914	Total			0.230414

A plan to deliver in sufficient volume for an entire model period of at least one car platform (a shared common design, including engineering and production methods) is required. It is not unusual for an OEM, once an innovation of this nature is selected, to insist on full production within nine months. If the first platform for one's product needs 1M parts per year, and the primary tool has an annual throughput much less than that, then there may be an issue. PVD tool component lead times of up to 12 weeks are a familiar occurrence. Develop a network of chamber and component suppliers early. In the case at hand, the automobile industry introduction cycle is often a couple of years. Complete turn-key systems can be fully operational at user facilities six months after an order is placed. With existing capacity, between 30 and 50 such systems can be produced per year. Arrangements are underway with a European supplier to at least double this capacity. A single system is capable of processing approximately 12,000 m²/year of parts.

TECHNICAL PERFORMANCE

Major automobile OEMs, including Audi, Volkswagen, BMW, Mercedes, Porsche, PSA, Renault, Ford, and Volvo continue to evaluate SuperChrome™ for both exterior and interior applications. For POP, OEMs have well-defined expectations for appearance and adhesion. They also have well-defined expectations for durability when exposed to chemicals, abrasives, and scratching, as well as temperature, humidity, and UV extremes. An explicit listing of all tests is outside the scope of this paper, but to date all tests have been passed.

An innovation is likely to have valuable attributes that the OEM or end user has not anticipated. The incumbent is likely to have subtle attributes that the OEM has unintentionally taken for granted. Marketing and sales people will want the technologist's support in making these characteristics explicit. In this case, the organization's PVD composite is lighter and more flexible, and laser etching can make it partially transparent. Some have noticed that the organiza-

tion's PVD challenger gives a different thermal transient feeling than POP.

VTI is waiting to learn if weight savings are going to be significant to the OEM (as shown in Table 1). Since SuperChrome™ uses an organic underneath the chromium rather than nickel and copper, one estimate places the weight of a SuperChrome™ plastic part at 88 % of a comparable electroplated part.

In applications where flexibility is a useful attribute, the challenger is superior to POP. Parts are often designed with mounting tabs or clips that must have a degree of flexibility. In electroplating operations, it is laborious and costly to mask these tabs to prevent coating. However, the electroplated material is so stiff that in some cases the tabs break off easily. With the organization's PVD composite, the tabs remain flexible. Another application that benefits from this attribute is automobile air bag covers. When these covers shatter, the exposed edge is no sharper than the plastic substrate. Electroplated material can expose a thick, sharp metal layer that can cause lacerations.

Another advantage of the challenger is the ability to create coatings with a day/night effect. Since the PVD layer is so thin, laser etching can economically produce dense arrays of holes in the PVD layer. The paint is transparent. If the substrate is also transparent, and the appropriate hole size and pitch are selected, the coating can appear to be a reflective chrome layer in daylight but also transmit light when backlit at night.

Some have observed that the PVD composite does not physically feel like a POP finish. This is tied to a conjecture that consumers value metal more than plastic. The tactile sensation includes several factors, including roughness, waviness, friction, temperature, and thermal conductivity. The main differences in this regard between metal, POP, and the PVD-coated part are thermal mass and thermal conductivity. A bulk metal feels cool to initial touch because it has

relatively high thermal conductivity and thermal mass. A finger has very sensitive temperature sensation. Consider the difference between touching a thermal insulator and a thermal conductor, each at the same initial temperature. Where the finger touches the insulator, the local surface quickly comes to the same temperature as the finger. Where the finger touches the conductor, the finger's heat is quickly conducted away to the rest of the colder part, and the part only slowly increases in temperature. How long this effect lasts depends on the heat capacity and total mass of the conductive portion of the part. On an electroplated plastic part, the relevant amount of material is only the metal coating, so the cool feeling is far less lasting than for a bulk metal part. The PVD composite coating behaves more like a metal to the touch.

SPECIFICATIONS AND STANDARDS

While developing the challenger (replacement coating), OEM specifications created for the incumbent must be considered. Each OEM is likely to have established its own specifications, which they share selectively with their existing suppliers. Suppliers usually lack permission to share these, so get them directly from the OEM as soon as possible. Expect those specifications to contain aspects irrelevant to the challenger. In the author's organization's case, some OEMs specify minutiae of an electroplated structure, including thickness of chromium, bright and semi-bright nickel layers, micro-discontinuity density of the chromium layer, and electrochemical potentials with the bright nickel a few millivolts anodic to both bounding layers. Such details have been found to reduce the appearance of corrosion in an electroplated product by allowing limited undercutting of the chromium as the bright nickel corrodes [6]. None of this detail relates to the PVD composite challenger. With only one electrically conductive layer, no electrochemical couples are created, there is no relative anode/cathode pair, and micro cracks are irrelevant to corrosion protection.

To attempt to perform all tests of each OEM is often impractical. In a development, for any performance attribute that is challenging, consider selecting a set of conditions that can discriminate significant improvement toward the goal, rather than the most severe of the conditions from among the panoply of options. A quantitative test provides guidance to altering process conditions that pass/fail tests lack. Once the processes yield a reliably good product, you can graduate to pass/fail tests whose purpose is to qualify a fixed process. When samples are submitted to OEMs for their evaluation, the risk of exposing deficiencies must always be gauged against being late to market. Common to

both new development and incumbent challenges, long-term exposure testing in south Florida or the Arizona desert may be required. Failure in those tests can significantly delay market entry, so you need to be highly confident of success. Get it right and plan for the time. In this case, early submissions to OEMs revealed issues with hydrolysis and abrasion. That led to development work that has resolved those issues.

Many OEM specifications will refer to standards from organizations like ASTM, ANSI, or SAE in the United States or ISO or DIN in Europe. Those standards were developed around the incumbent. Depending on relevance, the challenger may need to propose new specifications that are related to the existing ones. That means one may need to be familiar with many, perhaps dozens of them. Get familiar with the standards organizations and participate. This work is just beginning for the author's company and the introduction of the SuperChrome™ process.

END-USER PERCEPTION

The supply chain doesn't end until the product is in the consumer's hands. Again, expectations have been established by the incumbent. Maintaining and preserving the surfaces of a vehicle serves both aesthetic and economic purposes. Several decades ago, the majority of vehicle parts were steel, and the surfaces were protected either by paint or electroplated finishes. The surfaces themselves required some care. Soaps and polishes were developed to clean painted parts without leaving visible scratches. These were not effective for cleaning electroplated chrome, so more aggressive grit-based polishes were developed. Although these produced microscopic scratches in the chrome, the unaided eye saw a clean, shiny nickel underlayer and considered the surface restored. Over the past few decades, paint durability has continued to improve, as have methods of cleaning and caring for painted surfaces. Over the same time period, plastic parts have replaced many metal parts. Plastic does not require the same kind of corrosion protection as metal. For plastic parts, the shiny chrome finish has become decorative. The emphasis on functionality is now to preserve the decorative chrome itself. However, end-user perceptions have changed slowly. A plastic part with the appearance of chrome is often cleaned with the same needlessly aggressive grit as an electroplated part, when modern methods for cleaning paint are more suitable.

In an effort to evaluate cleaners, VTI tested coated plaques mounted on vehicles in upstate New York for 14 days of long-distance driving. Cleaners included conventional

chrome polish and automobile soaps, as well as toothpaste and vinegar. They were evaluated visually and microscopically to assess cleaning effectiveness and coating damage. Regular automotive soap did an excellent job of cleaning with no coating damage. The best rule is to clean the coating like paint.

CONCLUSION

Challenging an incumbent product for a technologist differs from introducing a totally new product. Both modes benefit from a phased, gated approach. In both modes, clearly defining the primary product and drivers will focus resources. The challenger of an incumbent coating does well to enter as early as possible to the existing supply chain. The challenging technologist must also crystallize the positive perceptions of the incumbent coating. Existing OEM standards set expectations for the challenger that a new product introduction does not face. Both approaches must address change at all levels, including the end user.

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