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Why Double Electrocoat and Powder?

In 1997, MerCruiser installed a new coating system. The impetus for the new coating system included a reduction in VOCs (Volatile Organic Compounds), a reduction in hazardous air pollutants, improved coating quality and lower cost. To achieve these goals and maintain the protection and coating flexibility required for our product, we selected a double electrocoat (epoxy primer and acrylic second coat) and powder topcoat. The system is flexible enough that we can perform any one of six coating sequences: 1) Pretreat only; 2) Pretreat and powder coat; 3) Pretreat and single electrocoat; 4) Pretreat, single electrocoat and powder coat; 5) Pretreat and double electrocoat; or 6) Pretreat, double electrocoat and powder coat. The variety of components processed in our plant necessitated a system that would satisfy many coating requirements.

Due to the complexity of our product line, we had to select a simple coating system that was flexible enough to handle complex shapes and extremely tight tolerances. Not all components can be electrocoated, nor can they be powder coated, and some cannot even be painted. Each part is individually evaluated to determine which of the six coating processes best suits the part.

Some criteria we use to evaluate how individual parts are coated in our new system include the following:

1. Can the aluminum part be hung to eliminate air pockets or pools? Hanging a part in the proper position enables pools to drain. It also allows air pockets to mask holes that require no paint. Air pockets prevent coating on some areas of a casting. So these areas are neither pretreated nor electrocoated. Pools result in excessive chemical loss due to dragout, and may cause boil-out (drips and runs from boiling pools of paint).
2. Is electrocoat masking required? If you mask, the masked areas will not receive a pretreatment in our system.
3. Will the part be used in an external application? If the part will be exposed to sunlight, it needs an acrylic electrocoat.
4. How uniform is the part? Part shape highly impacts the part's ability to hold tight tolerances uniformly and on the ability to apply powder coating.
5. Does the part function accommodate machined surfaces that are electrocoated? In many situations it is possible to oversize a bore or threads and buildup the dimensions with electrocoating. Sometimes it is possible to coat threads without any modification to the original thread dimensions and without any detrimental effect on assembly or performance.
6. Are there any conductivity concerns? Electrocoating covers all surfaces and may insulate areas required for continuity/conductivity.
7. Are there any large holes or surfaces that would require masking? Unless it is a small round hole, it is difficult to mask for electrocoating. In a double electrocoat process, the masking must survive two electrocoating cycles without failure.
8. Will the part receive a finish coat on our liquid line? The liquid topcoat adheres well to the single epoxy electrocoat, but poorly to the acrylic electrocoat.
9. Are there any Faraday cage areas? It is extremely difficult to get an even coat of powder in narrow crevices.
10. Can the coating requirements of a part be met without applying powder? Avoiding powder coating increases throughput of this system because parts can be "stacked."

To better understand how each of these questions impacts our coating choice, it is important to understand the benefits and shortcomings of each phase of our new process. Each process, (pretreat, first electrocoat, second electrocoat and powder coat) contributes to the product, and each process and combination of processes have advantages and disadvantages.

Advantages and Disadvantages 100% UV coverage (double electrocoat).

In a marine environment, stern drives are exposed to sunshine and salt year round. For corrosion protection, we use an epoxy primer because of its excellent adhesion to metal. Unfortunately, epoxies breakdown when exposed to ultraviolet radiation. Loss of gloss, color and the development of a powdery film are associated with the breakdown process. A common way to protect the cosmetics of an epoxy-coated part is to apply a coating of a UV-stable resin. With proper formulating, polyester, polyurethane and acrylic resins all protect the epoxy from UV radiation.

Various application methods are available. However, of powder, liquid and electrocoat, only one guarantees 100% UV protection, electrocoating. Testing at MerCruiser's corrosion facility has demonstrated that thin applications of a topcoat will lead to breakdown of the bonds between the epoxy electrocoat and a topcoat, causing the topcoat to peel. These areas of thin coating had an acceptable appearance after coating; however, the film build was insufficient to protect the epoxy primer from UV. On uniform parts, or parts requiring a heavy film build, this would be less of a concern, since it is much more likely that a uniform topcoat could be applied that would be sufficient protection for the casting. Manual touch-up guns could also be employed to "hit" the light topcoat areas left behind by the automatic spray guns. This can be labor intensive. On parts that are not uniform, applying UV-stable electrocoat for the second coat guarantees a uniform "sun block" for protection with minimal added labor.

Topcoat color flexibility. One disadvantage of electrocoating is the inability to inexpensively switch from one color to another. Two methods that have been used to provide multiple electrocoating color capability include two separate electrocoating systems that slide under the conveyor for the desired color (single electrocoat), and a second method that uses a power-and-free conveyor to route parts to the desired topcoat color (double electrocoat). If you have high volumes of a few colors, this may be the most cost-effective method. Both methods still limit color flexibility and the ability to expand color choices. A less expensive and more color flexible alternative is to use a different process to apply the topcoat. Either a liquid or powder topcoat will perform well on top of an epoxy electrocoat primer and offer color change flexibility. We elected to use a powder topcoat.

Surface blemish coverage. Electrocoating uniformly coats every nook, crevice, drag mark, scratch, etc., with a very thin coating. For products with a fine surface finish, this presents a cosmetic advantage, no runs, drips or other common coating defects. However, if the finish of a product has surface blemishes the manufacturer would like to cover, it is not easily done with electrocoating. For example, some of our products are electrocoated only if their placement or function does not require a blemish-free finish. In these cases, the coatings are defect free, but the details of a diecasting process are still clearly visible. This does not mean that minor blemishes cannot be hidden by electrocoating. The thicker the coating, the more blemishes it hides.

2.--Coating Adhesion Tensile Test

Trial	Failure (psi)	Notes
1	2862	separation at adhesive/paint interface,**small amount of paint removed**
2	2553	separation at adhesive/paint interface, **small amount of paint removed**
3	1898	separation at adhesive/paint interface, no paint removal
4	2957	separation primarily at adhesive paint interface, **small amount of paint removed**
5	2661	separation at adhesive/paint interface, no paint removal
6	1868	failed at adhesive/paint interface, no paint removed
7	2339	separation at adhesive/paint interface, no paint removed
8	2618	separation at adhesive/paint interface, no paint removed

The additional two mils of powder coating cover many of our casting blemishes that remain visible after electrocoating. The powder flows in or bridges across minor blemishes in the casting surface and has less of a tendency to follow the contours of blemishes.

Uniform coverage/film build control. Another advantage of electrocoating's uniform film build is the capability to hold relatively tight tolerances. This has enabled us to reduce the amount of masking on surfaces and holes traditionally masked for spray application. These surfaces include threads and bearing bores for some types of bearings. We oversize the bores by the thickness of the coating and then coat back to within the original tolerance. Needle bearings are a notable exception because extremely tight tolerances are required for bearing assemblies that cannot be held by the electrocoating process. Endurance testing of six units with oversized bores built-up with electrocoat resulted in a needle bearing failure rate of 50%.

It is possible to press bearings in over paint; however, there are limitations to the amount of stress that can be applied to electrocoated mating surfaces. At certain levels of compressive/shear stress, the layers of the coating begin to delaminate (Figure 1). Separation occurs between the two layers of electrocoat and at the electrocoat/ aluminum interface. Under the forces required to cause delamination, the layers of coating have not noticeably compressed or distorted, resulting in a removal force that was roughly equal to the installation force. No paint was removed during installation. Paint was removed only during the removal of the bushing. By using gear lubrication to reduce the shear stress, we are able to assemble the bushings with acceptable levels of press without damaging the coating in the bore.

In order to develop standards for adhesion, we performed tensile tests (Figure 2) on the adhesive properties of the coating to the substrate. We glued a one-inch square-steel block to an electrocoated surface and placed the glued assembly on a tensile tester to test the coating adhesion. Although the test itself was not conclusive because the adhesive failed, it did give some indication of what to expect if a better adhesive can be found and the testing continued.

Heat distortion. Another factor that may affect coating tolerance is the cure cycle for the coating. Depending on the substrate coated, the cure temperatures may affect the size and shape of the part. The effects of cure temperatures on the substrate, aluminum diecast, can actually cause diameters to grow during the coating process, up to 0.0005 inch on a three-inch diameter. A typical electrocoating cure cycle may be as high as 400F for 40 min.

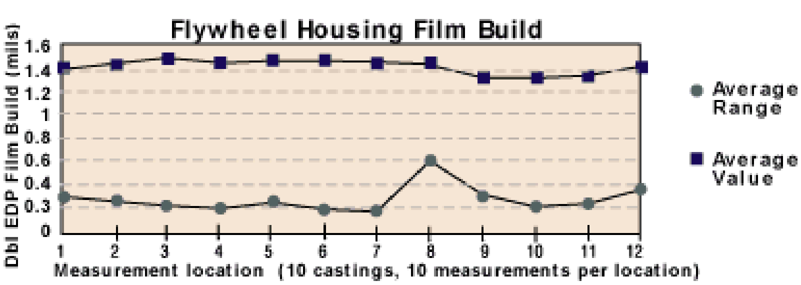
Stack-up tolerances. Although electrocoating holds relatively tight tolerances, the stack-up of tolerances of two coats of electrocoat plus the machining tolerance can interfere with product performance. It is necessary to investigate how electrocoating affects product performance on a case-by-case basis, and determine what part modifications/design changes may be required. Figure 3 shows coating stack-up tolerances that were developed from 16 months experience with a batch system at our facility. The operators of the batch system took daily measurements on specific locations of each type of casting.

3.--Estimated Coating Tolerance Guidelines

Coating Capabilities	Pretreat Only	Pretreat & Epoxy Coat	Pretreat & Acrylic Coat	Pretreat & Double Coat	Pretreat & Powder	Pretreat, Epoxy E-Coat & Powder	Pretreat, Acrylic E-Coat & Powder	Pretreat, Double E-Coat & Powder
Optimal Coating Thickness	0	.0008	.0008	.0016	.0020	.0028	.0028	.0036
Coating Tolerance per Surface	7.000	7.002	7.0002	7.0004	+.0020	+.0022	+.0022	+.0024
					-.0005	-.0007	-.0007	-.0009

After installing our new system, we were able to verify the findings from our batch system. The product we tested, a 17-inch flywheel housing, is one of our higher volume parts, about 400 a day. The aluminum casting was coated with double electrocoat. Figure 4 summarizes our data on the flywheel housing. A total of 1,200 measurements were taken across 10 castings at 12 locations, with 10 measurements at each location. Note, measurement location eight on the castings was located on the edge of a curved surface where it was difficult to obtain measurements.

Figure 4 shows that our new system appears to provide results similar to our batch system. Our specification for double electrocoat is 0.0016 inch 7 0.0006 inch. The lower than optimal coating thickness is readily compensated for by adjusting the coating application voltage levels.

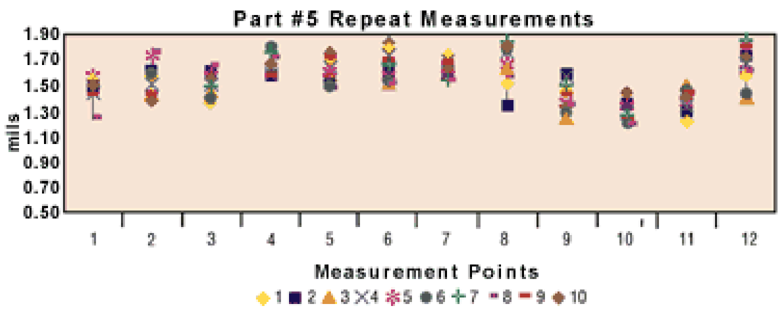


4. Initial Capability Testing Summary.

In *our system,* a 25-volt increase in application voltage results in a 0.0001-inch increase in average coating thickness. When mentioning *our system,* I am referring to the design of the tank and the chemical balance of the paint. Factors that can affect coating thickness include tank size, number of electrodes and location, maximum current, percentage solids, paint temperature, solvent levels, pH, product surface area in the tank, etc. Fortunately, the electrocoating process is forgiving and relatively easy to control for most applications.

Challenges of measuring film build. For most of our data collection, we used a common non-invasive film-build-measuring device. Unfortunately, because of the casting and the tool, we did not achieve the desired precision when measuring the raw part.

Figure 5 contains measurements taken from a single casting (one of the 10 castings summarized in Figure 4). Each Measurement Point had ten successive measurements taken. The variations of the measurements at each location are due to the inability of the operator to hold the probe perpendicular, relocate the probe in the same spot, and/or the substrate's surface irregularity. To measure film build and test process capability routinely, we needed a repeatable method. To minimize variations due to measurement error, we created a fixture to hold a special test panel and maneuver a probe in a repeatable motion.



5. Initial Capability Testing Summary.

Capability studies continue using this new measuring system, which enables us to understand how tightly we can control the film build in our electrocoating system. We continue to spend our energies understanding the limitations of the film. This will enable us to further streamline our production process and improve corrosion protection.

Masking required for electrocoating. Masking for electrocoating can be difficult. Since the method of coating requires dipping the part in a liquid bath, you have the potential to create large pressure differentials at the interface of the masking and the part surface, which can lead to leaks. To protect the surfaces from electrocoating, we have tried many methods of masking: high-temperature silicon plugs, aluminum plugs with silicon O-rings, grease, mating parts, blind holes, etc. Each method has its advantages in different applications.

One effective method is to mask a surface using blind holes or blind cavities. When a part is dipped into a bath, the blind hole is oriented so that the opening is pointed down. An air pocket forms, preventing the coating from reaching the surface. On complex geometry it is difficult to take advantage of air pockets without part modification. We had one casting that when oriented to prevent pooling created an air pocket that masked an adjacent surface we wanted to coat. We had to create holes in the top of the air pocket to allow the air to escape, which, consequently, required product testing to ensure that there would be negligible impact on performance.

If it is possible to use standard high-temperature silicon plugs to mask small holes, the low durometer of many silicon plugs helps ensure a good airtight seal. Threaded areas can be masked using the mating hardware. In this case, the surface tension of the water in the threads from previous processing minimizes the amount of paint that will seep in. Removing the mating part will also ensure that the threads are prepared for assembly.

Some non-conductive, high-temperature greases have been tried with varying degrees of success. By "smearing" grease on the part surface, the greased area is insulated, preventing the coating of the area. However, extensive use of such products is discouraged since oils in the grease can contaminate the bath resulting in coating defects.

Large cavities, unless they are blind, have proven to be impractical to mask, and the technology is not repeatable in a production environment. If large cavities cannot be successfully masked, then machining after painting is used. This is not practical, but repeatable.

Masking required for powder. Because powder coating application is similar to liquid spraying, similar masking techniques can be used. Moreover, there have been few breaks from this paradigm. If you design your system with nature of powder coating in mind, it is possible to design your system to take advantage of the unique attributes of powder coating application. For instance, it is possible to remove the masking prior to cure. This has several advantages:

- Reusable masking can be easily created with inexpensive materials since the masking is never exposed to high oven temperatures.
- No expendable masking to purchase.
- No sharp ridges at the powder and masking interface. Since the masking is removed prior to the curing process, the powder is allowed to gradate or flow ever so slightly toward the unpainted surface, creating a nice smooth transition.
- Powder can also be removed prior to the powder oven using detail vacuuming implements. By vacuuming off the powder it is possible to eliminate the masking step entirely. Note, this will only work in certain situations and requires a skilled operator.

To take advantage of the removability of powder, it is necessary to design your coating system with a masking area prior to the powder booth (after part cleaning or electrocoating), and a demasking area after the powder booth and prior to the oven. In addition, it is necessary for rework procedures to be established for dealing with paint surface imperfections caused by improper demasking or "touches" that occur during the demasking process.

Hangers. Electrocoating saves resources during the coating process. However, there may be an increase in hanger burn-off requirements for some products and applications. On the plus side, the hangers we use in single electrocoat applications do not require burn-off. Sharp edges in hook design and the self-insulating properties of an electrocoat ensure good continuity with the part and minimal film build on the hanger. If a part does not coat the first time, it is easy to discriminate, and we can send it back through the coating system.

With the application of a second electrocoat, we were not quite so fortunate. Although the same properties of single electrocoat hangers apply to double electrocoat, there is a problem when the occasional casting does not take the first coat (this only happens when the castings were loaded on dirty hangers). Often a casting that did not take the first coat will take the second coat. This may be due to the additional travel and vibration that the casting receives during transport to the second coating application or the higher voltage levels of the second electrocoat process. In either case, it is difficult to tell which castings did not receive a prime coat, and there is the risk of selling non-primed parts.

There are ways to minimize this effect without burning off the hangers every time. Minimizing the number of contact points and having a denser, heavier part are two ways to break through the thin coating on the hanger. Reducing the number of contact points on the hanger puts more load on the remaining contact points, improving the likelihood that they will break through any coating insulating the part. Many of our castings are lightweight aluminum, which makes it difficult to achieve continuity without burning the hooks.

Cost effective. With single or double electrocoat, we can increase production by "stacking" parts. To stack parts, we place them on hangers in a fashion that would hide surfaces from traditional coating methods. Consequently, the throughput gains are not as great for products that require a powder topcoat. Our ability to stack parts depends on the size of the part and the coating required. Electrocoating only on parts less than two inches, we were able to go from coating 100 per min to coating 500 per min. Even some of the larger castings have had an increase in throughput. One 18-inch part went from coating eight per min to just under 24 per min. Most of the gains in coating throughput are due to the ability of the castings to be "stacked" in the product envelope. And, with electrocoating no "touch up" painting is required.

Skill. More analytical skill is required to balance an electrocoating tank than to operate a liquid or powder booth. The proper function of an electrocoating tank is dependent on many factors directly related to the chemical balance of the electrocoat. We currently monitor percent solids, pH, paste/binder ratio and solvent levels in our two tanks. Each parameter may need daily adjustment; it depends on the amount of product coated in the system. It is up to the customer to learn how to compensate for changes in the chemical balance. An improperly balanced tank can lead to poor adhesion, poor film build, too much film build, no film build or other cosmetic defect.

Environmental benefits.

- Lower VOCs than a low-solids liquid spray.
- Better than 95% coating use in both electrocoating and powder coating
- No zinc chromate primer.

Biggest challenge: Optimizing the product to take advantage of electrocoating. Our primary objectives were to reduce emissions and labor. Both electrocoating and powder coating gave definite advantages over liquid spray in achieving these goals. When selecting a new coating system it is important to remember that the product designers probably had a coat of liquid spray paint in mind when they originally designed the part.

Switching to electrocoating is as much a product change as it is process change. If we did not have any threaded holes or tight-tolerance machined surfaces, the only thing we would have changed on our prints would have been to remove the no paint symbols. However, to minimize the use of masking, we have had to rethink how we process our parts. The nature of electrocoating and powder coating has enabled us to do things that were not possible with a liquid spray system.

Not all companies that change from a traditional spray system to an electrocoating system are going to require the level of product modification and evaluation that we have. However, it is still important to remember process differences electrocoating offers when designing new products or switching to a new process. You need to break away from the paradigms developed through years of liquid spray application. **PF**

All information contained within this document results from research conducted at Mercury Marine Facilities from 1986 through 1997.