A PERFORMANCE EVALUATION OF MODERN SURFACE FINISHES FOR ZINC DIE CASTINGS

Zinc *Protects!*

Why Zinc Castings?

Zinc die castings are a unique choice for countless decorative and functional applications. Zinc is a relatively dense metal, which has a feel of "substance" and durability. Zinc casting alloys are also stronger than all but the most highly reinforced molded polymers. Zinc's hardness, self lubricating properties, dimensional stability and high modulus make it suitable for working mechanical parts, such as gears and pinions, that would be less durable if molded from polymers. Zinc can be die cast at moderate temperatures thus providing significant energy and processing savings over other metals and engineering alloys. Zinc also accepts a broad assortment of finishes, from chemical conversion treatments to electroplating to sprayed and baked polymers.

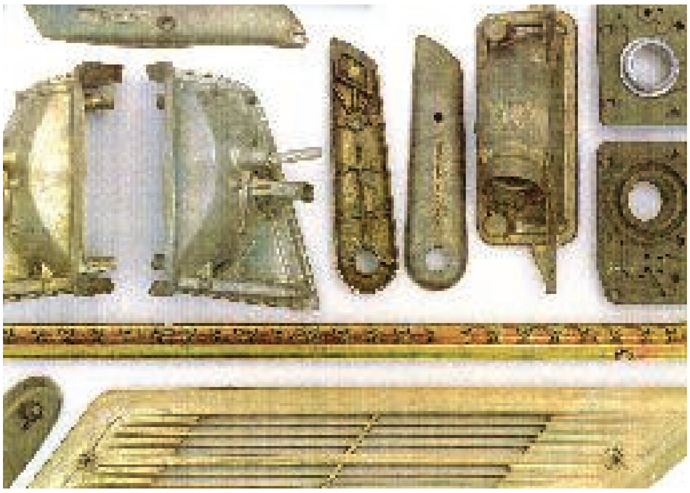
When a finish is properly selected and applied to die cast zinc, almost any desired aesthetic characteristic and coating durability can be achieved. Zinc castings can be made to look like solid gold, weathered brass, stainless steel, and even leather. The majority of zinc die cast applications are not exposed to corrosive environments and the aesthetic requirements of the part defines which finish should be used, which in many cases means no finish at all.

For applications where the service environment is aggressive, such as marine hardware, external automotive parts, and items for use outdoors at industrial sites, corrosive attack can result in white rust, black staining, or, in some cases, flaking and peeling of the finish due to corrosion of the underlying zinc. For such severe environments the manufacturer must select corrosion resistant finishes.

The Study

The following information is from results of an investigation[1,2] conducted by the International Lead Zinc Research Organization (ILZRO) to evaluate the performance of modern protective and decorative finishes commonly used on zinc die castings. The investigation was performed by the Corrosion and Materials Research Institute (CAMRI) in Newark, Delaware, USA.

The ILZRO study described here provides a comparison of the performance of different finishes used to protect and provide an aesthetic finish to zinc die castings. The study looked at two different performance criteria – the ability of a finish to protect the underlying zinc against corrosion, and the ability of the finish to maintain its initial aesthetic properties upon exposure to corrosive conditions. This information is intended to supplement the data found in earlier publications[3] and to allow an end user or parts manufacturer to select the optimum finish properties for a given application.



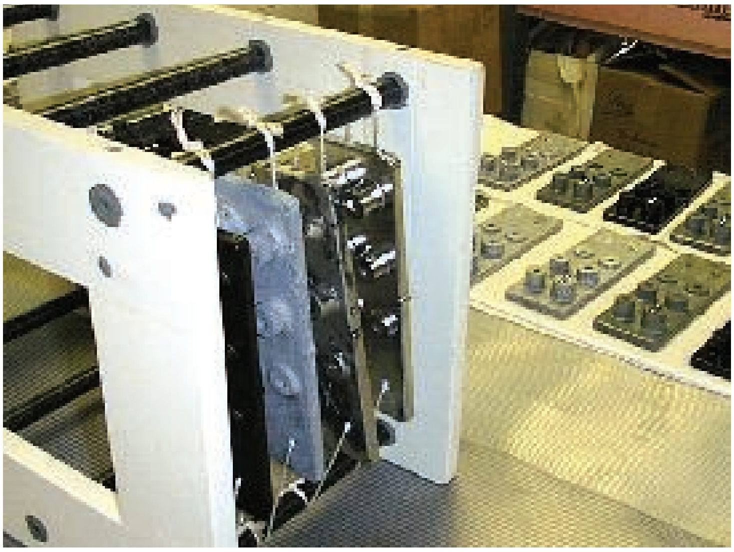
Test Procedures

The test panel used in this study was a “bolt boss plate” that incorporates flat and curved surfaces, rounded and sharp edges, through-holes of various diameter-to-depth ratios, and inside and outside corners. These test panels were drilled and tapped, and stainless steel screws added after finishing but before test exposure. An “X” was scribed through the finish, to expose the underlying zinc.

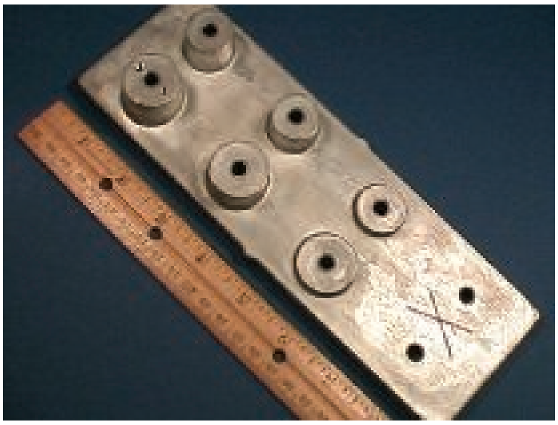
In a preliminary phase of this study, die cast zinc panels coated with a chromate conversion treatment, with a powder epoxy, and with an “automotive” grade of copper-nickel-chrome electroplate, were subjected to three different accelerated corrosion tests.
These tests were as follows:

- The standard ASTM B-117 salt spray test for 500 hours
- The newer ASTM G85 mixed salt cyclic fog test – also for 500 hours
- The CAMRI test (originally used at DuPont in the 1980’s to evaluate finishes for industrial fasteners) which exposes panels to a constant 100% relative humidity at 50° C or 122° F with weekly misting of the panels with a solution of 1% sodium chloride and 1% sodium sulfate.

Panels subjected to this test were exposed for up to six months, with interim evaluation at one and three months.



Test rack and panels outside humidity chamber



Top side of test panel before finishing and corrosion testing

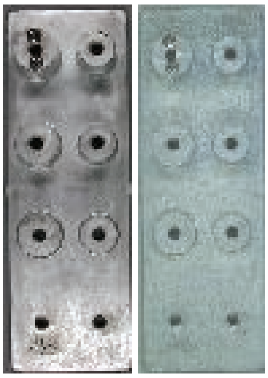
This preliminary phase found that, while the two ASTM tests did produce white rust on portions of some panels, the CAMRI test produced mixed corrosion products and physical failures not seen in either of the ASTM tests. More importantly, the appearance of the corrosion and the localized physical failures of the finishes appeared similar to what actually occurs on coated zinc panels after extended exposure to corrosive environments. Based on these observations it was decided to use the CAMRI test method for the overall study. It was further observed that while the six month test clearly gave the most dramatic failures and corrosion, all of the six month failures were also observed in the three month inspection. It was decided, therefore, to run the final tests using the CAMRI protocol for three months. All test sample pictures shown in this report are from the final phase using the CAMRI protocol.

One major advantage of the CAMRI test is that it requires no special equipment. For example, anyone with a low-temperature (50° C or 122° F) oven can fashion a humidity chamber out of an aquarium with a glass top, place a layer of gravel and water in the bottom to maintain saturated humidity, and apply the weekly spray of mixed salts with a hand spray bottle available at any hardware store.

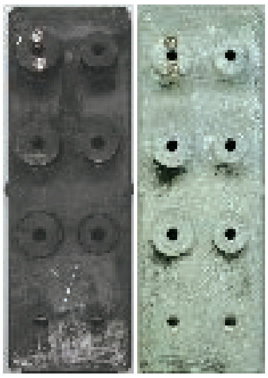
To put the CAMRI test in perspective relative to actual field exposure, DuPont studies found that a three month test in the laboratory equated in nature and severity to roughly one year of actual exposure at a severely corrosive chlorofluorocarbons plant site on the U.S. Gulf Coast, or three to five years at inland chemical plant sites.

Test Panels

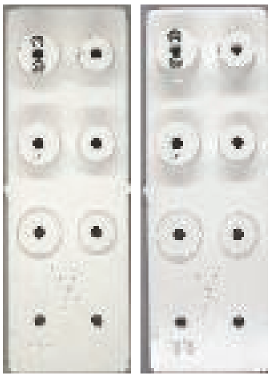
Appearance of finishes before and after three month exposure to CAMRI test


Before After

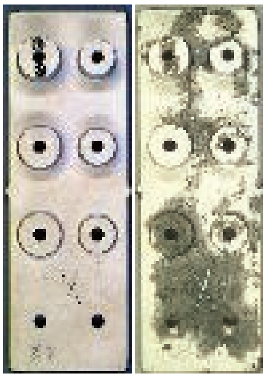
Unfinished Control


Before After

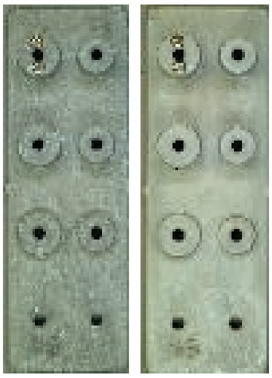
A) Zinc Black


Before After

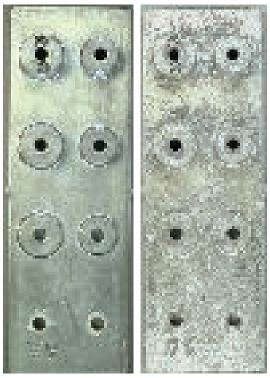
D) Sprayed & Baked Liquid Coating


Before After

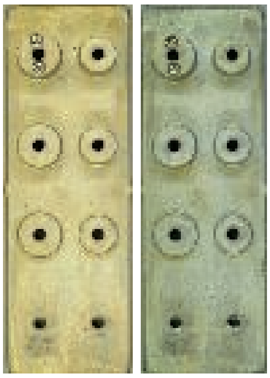
B) Cu-Sn-Zn Electroplate


Before After

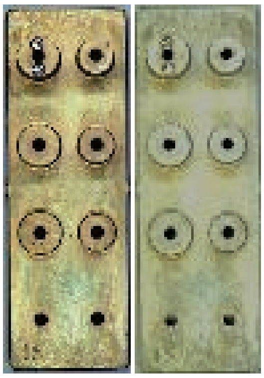
C) Trivalent Chromium + sealer


Before After

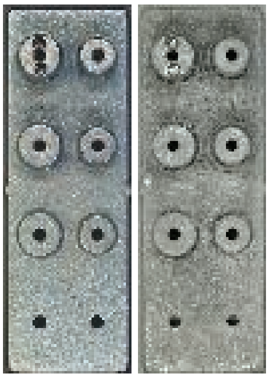
C) Zn Plate, Trivalent Chrome + sealer


Before After

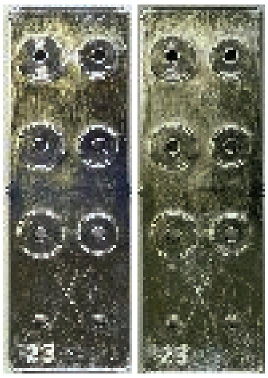
E) Cr^{+6} Conversion +sealer


Before After

E) Cr^{+6} Conversion - no sealer


Before After

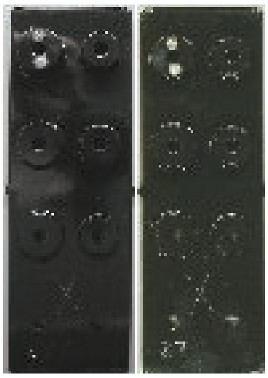
F) Mechanical Plate


Before After

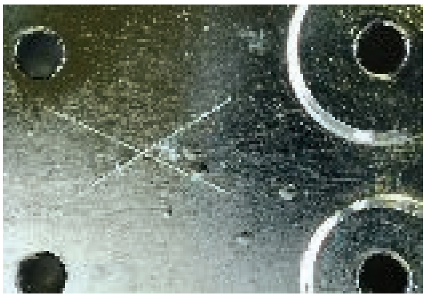
G) Cu-Ni-Cr Electroplate


Before After

H) Powder Epoxy


Before After

I) Urethane Resin E-Coat



Blisters formed on "dual nickel" Cu/Ni/Cr plate after three month exposure

Finish Performance Evaluation

Two zinc alloys were tested, No. 3 and No. 5. While there were slight differences in the performance of the chromate conversion finishes between the two alloys, the differences were small and not consistent. It was concluded that there is no significant difference between these two alloys as far as resistance to corrosive atmospheres is concerned. All panels were tested "as finished", with no heat treatment.

Scoring of the finishes (Table 1) was done by two CAMRI corrosion technologists who inspected the panels together and agreed upon scores for individual panels. The scoring was based on a maximum value of 10 with points deducted for observed imperfections in the finish. Each panel was judged against an unexposed panel with the same surface finish along with unfinished control panels that had gone through the same test exposure. The finishes were rated based on their ability to protect the panel against corrosion during the test compared with unfinished zinc panels. While scoring the panels it became apparent that some finishes showed localized breakdown but still maintained the aesthetic properties of the coating while other finishes protected the entire surface of the sample but became quite unsightly and would be judged for many applications as having failed. It was decided to score each finish in two categories: (1) their ability to physically protect the underlying zinc against corrosion; and (2) their ability to maintain the original aesthetic value of the panel surface. Each of the scores was on a scale of 0 (no better than the unfinished control) to 10 (visually perfect).

e-coat finish after three month test exposure

Performance Ranking of Finishes

Table 1

FINISH CATEGORY AND DESCRIPTION	CORROSION PROTECTION			PRESERVING AESTHETICS
	Zamak 3	Zamak 5	Average	
E - chromate conversion, no sealer	5	6	5.5	6
E - chromate conversion, no sealer	6	4	5	4
E - chromate conversion with sealer	7	5	6	6
C - clear chromate (No Zn) with sealer	2	1	1.5	4
C - clear chromate with sealer	3	2	2.5	2
C - Zn plate, trivalent chrome, JS 500 sealer	4	4	4	3
G - "dual nickel" Cu/Ni/Cr plate	5	6	5.5	7
G - "marine" Cu/Ni/Cr plate	8	8	8	9
F - zinc-tin mechanical plating	9	9	9	6
H - powder epoxy 10-7011 on non-blasted panel	8	9	8.5	9
H - powder epoxy 10-7011 on grit-blasted panel	9	8	8.5	9
H - polyester powder coating	9	9	9	8
D - 4510 liquid polyester coating	5	4	4.5	5
I - urethane resin e-coat with nanoparticles	9	10	9.5	10
I - urethane resin e-coat without nanoparticles	9	9	9	9
I - urethane resin e-coat without nanoparticles	10	9	9.5	10
D - low friction coating, phenolic resin	4	5	4.5	5
D - low friction coating, polyamide-imide resin	3	3	3	4
B - copper – Cu/Sn/Zn electroplate	6	6	6	1
A - zinc black coating	1	1	1	2

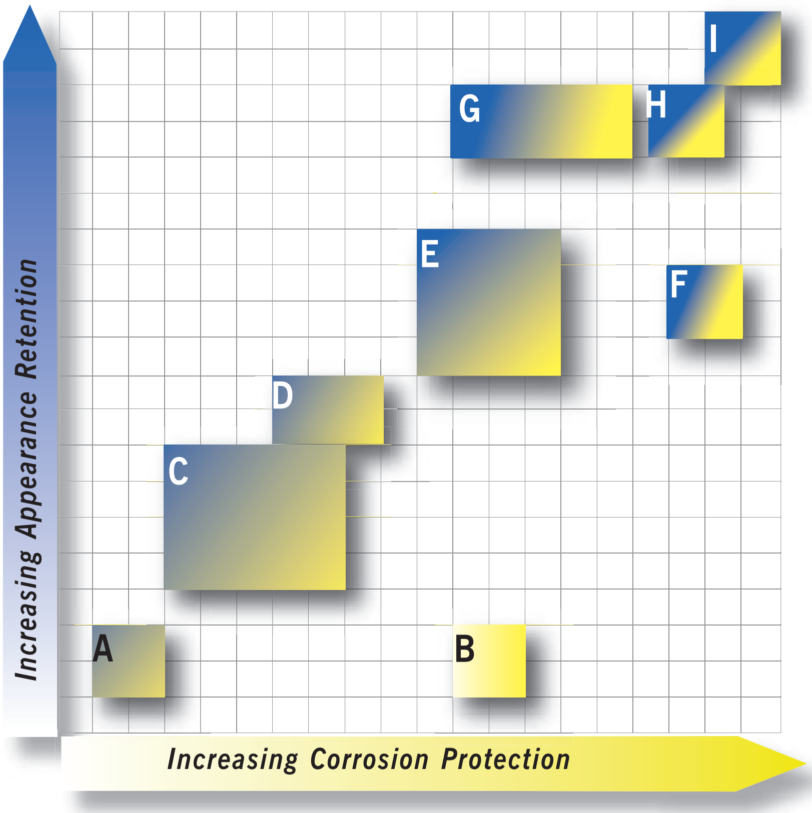
Selecting a Finish

The first step in selecting a finish for zinc die cast parts is to determine how much corrosion resistance the part will require. If it is a part to be used indoors in a dry application, corrosion resistance is not a factor. For indoor parts that are to be frequently wetted in service, such as faucet handles and shower heads, as well as parts to be used outdoor in inland rural areas or non-industrial, non-coastal sites, only moderate corrosion resistance is needed. For hardware for boats and marine facilities, constantly wetted parts, and parts to be used outdoors in industrial applications, corrosion resistance should be the first consideration.

The second issue is whether the part needs a decorative finish, or whether a purely utilitarian finish is adequate.

Once these issues have been decided, refer to the chart below that shows relative performance for the various types of finishes. For better corrosion resistance select finish types toward the right of the chart. For better aesthetic retention consider finishes closer to the top of the chart. If neither of these factors is important for your particular application, don't limit yourself by selecting properties not required – this will only reduce your options and probably cost more than is necessary.

Table 2



A Zinc Black
B Cu-Sn-Zn Electroplate
C Clear Chromate and Trivalent Chromium
D Sprayed & Baked Liquid Coatings
E Hexavalent Chromium Conversion
F Mechanical Plating
G Cu-Ni-Cr Electroplating
H Epoxy & Polyester Powder Coatings
I Urethane Resin E-Coats

Finishes Tested

The types of finishes included in the study are described below in approximate increasing order of performance, with the lowest performing finishes listed first.

A Zinc Black. This is a process in which a relatively thick black phosphate film is imparted to the casting to protect against humidity and moderately corrosive atmospheres. This finish is not usually proposed as a stand-alone corrosion barrier, but rather is a paint pre-treatment. Unlike the smooth, dense blacking that is used widely on steel guns and tools, the blacking on zinc is dull and somewhat powdery in consistency. Zinc blacking by itself did not offer significant protection in this test, and was largely dissolved or washed off by the periodic wetting of the panels with mixed salt solution.

C & E Chromate Conversion Coatings. These are chemical immersion treatments which produce a thin protective film on the zinc surface. They are intended primarily to protect parts during storage or in mild (e.g. indoor) environments or, like the zinc black, to provide an optimum surface for adhesion of subsequent paint or other organic finishes. Conversion coatings are sometimes followed by a sealer or lacquer to enhance their performance and extend the range of their applicability. In these tests it was observed that the hexavalent chromate conversion coatings, with or without a sealer, performed much better than did trivalent chrome or "clear" chromate finishes.

D Sprayed & Baked Liquid Coatings. This includes a broad spectrum of different chemistries, including epoxies, polyesters, phenolics and urethanes, just to mention a few. The test matrix included low friction fluoropolymer coatings not primarily intended for protecting against corrosion. The coatings were applied approximately 25 to 50 microns (1-2 mils) thick, and provided only moderate protection. Some also tended to discolor or become generally unsightly during the test. There are many thicker industrial sprayed and baked organic coatings on the market that undoubtedly would have performed better in this test.

B Copper-Tin-Zinc Electroplate. This is a proprietary process that forms a dull, silvery finish on the zinc. In these tests it offered fair protection to the zinc, but the finish itself developed an unsightly, sometimes black, splotchy appearance. The overall thickness of the finish in this case was about 25 microns (1 mil).

G Copper-Nickel-Chrome Electroplate. This has been one of the workhorse finishes for outdoor and corrosive applications for many years. On zinc it begins with a thin layer of cyanide (non-acid) copper flash to protect the zinc against the acidity of subsequent baths. Next comes a thicker layer of acid copper plate, which serves to make the surface more uniform and assures good electrical conductivity. This is followed with one or more layers of nickel, which provides a continuous corrosion resistant barrier. Finally one or more layers of chromium are applied to give the desired shiny "silvery" appearance and to protect the nickel against mechanical forces such as wear and erosion. Electroplating has one disadvantage vs. non-electrical processes in that it is difficult to get plated metal into inside corners and holes. This can be largely overcome by using what are called "conforming" anodes, but these make the process more expensive. A two-nickel layer system commonly referred to by some as "automotive" grade chrome plate, plus a three-nickel-layer version used for more stringent applications and sometimes referred to as "marine" grade, were tested. There was, a noticeable improvement in performance with the "marine" vs. the "automotive" grade plating. There was also, with both systems, a noticeable incidence of local failures at inside corners – presumably indicative of thinner plating application at those locations.

F Mechanical Plating. This name is somewhat misleading, as this general category of finishes involves placing the parts in a drum with the desired mixtures of metal powders and a chemical "activator" and tumbling the parts until the desired thickness of coating builds on the part by mechanical plus chemical action. It is possible in this way to coat with an "alloy" of almost any desired metals, including zinc+tin, zinc+cobalt, zinc+iron and zinc+nickel. Zinc is almost always included because it responds especially well to the mechanical/chemical bonding process. This process has a distinct advantage over electroplating in that materials can be applied very uniformly on all surfaces, including on inside corners. The use of different metal combinations offers different aesthetics (colorations). This process was originally developed with zinc alone – a process usually applied to steel parts and called "mechanical galvanizing". The zinc+tin alloy was tested with a coating thickness of approximately 50 microns (2 mils), including a topcoat with trivalent chrome and clear sealer.

H Epoxy and Polyester Powder Coatings. These polymeric coatings are applied as powders in a dry electrostatic process, and subsequently "fused" in an oven. This process offers environmental and personal hygiene advantages over wet sprayed and baked coatings because there are no solvents to drive off. Because the powder application is usually an electrostatic process, sprayed powder coatings also provide better buildup at edges than do wet-sprayed polymers. On the down side, for this same reason it is difficult to get coating materials into deep recesses and inside corners although this problem was not observed with the sample geometry used for these tests. In fact, no local failures of these coatings were observed at inside corners, as had been the case with the Cu-Ni-Cr electroplating. In these tests, both the epoxy and the polyester powder coatings did much better than the sprayed liquid coatings. While powder coatings are gaining an excellent reputation as corrosion protecting barriers, it is also true that these powder coatings, at 75-100 microns (3-4 mils) were much thicker than the liquid coatings evaluated in this program.

It is generally accepted that grit-blasting a part gives better coating adhesion and, therefore, better coating performance in aggressive service conditions. The blast finish on some of the epoxy-coated panels produced only about a 25-micron (1 mil) surface profile – and did not enhance performance in these tests as compared to a non-blasted zinc surface. Most coating manufacturers recommend much deeper blast patterns – typically 50 to 75 microns (2-3 mils) for optimum coating performance. Such an aggressive blast, however, may result in warpage and/or a matte coated surface, so should be tested and evaluated on your particular part before specifying heavy blast preparation for a powder coating.

I Electrophoretic Urethane Coatings. Also known as "e-coats", the three electrophoretic coatings evaluated here all did exceptionally well. Measuring only about 20-25 microns (0.8-1 mils) in thickness, these finishes defied the rule about thickness being needed for good corrosion protection. One of the finishes tested contained ceramic "nanoparticles" to give added abrasion and wear resistance, and a black color. The nanoparticles did not show any measurable effect on corrosion resistance compared to the regular urethane resin e-coats.

Contributors to this Study

ILZRO acknowledges the North American Die Casting Association (NADCA) www.diecasting.org, the international zinc industry and Eastern Alloys Inc. and Mazak Ltd. for their financial support of this study. ILZRO also thanks the Corrosion and Materials Research Institute (CAMRI) for their excellent work performing the corrosion tests and reporting the results. And, ILZRO thanks the following companies who contributed materials and applied finishes to the samples tested in this program:

Intermet Technical Center, Lynchburg, Virginia, USA
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Allied Finishing Grand Rapids, Michigan, USA
Atotech USA, Inc., Rock Hill, South Carolina, USA
ClearClad Coatings, Harvey, Illinois, USA
e-Black Solutions, Toronto, Ontario Canada
Erie Plating Co., Erie, Pennsylvania, USA
Finishing & Plating Service, Kenosha, Wisconsin, USA
Grove Plating Company Inc., Fox River Grove, Illinois, USA
Umicore Research, Olen, Belgium

References

1. Goodwin, F.E., Tatnall, R.E.& Corbett, R.A., "Evaluation of Corrosion Tests for Zinc Die Casting Surface Finishes", presented at CastExpo '05, St. Louis, Missouri, USA, April 16-19, 2005, North American Die Casting Association, Wheeling, Illinois, USA.
2. Goodwin, F.E., Tatnall, R.E.& Corbett, R.A., "Updated Performance Data on Modern Surface Finishes for Zinc Die Castings", presented at CastExpo '06, Columbus, Ohio, USA, April 18-21, 2006, North American Die Casting Association, Wheeling, Illinois, USA.
3. Zinc Alloy Diecastings – Selected Corrosion Preventative Finishes, Eurozinc, revised by Mazak Ltd. 2004.

Zinc Protects!

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