# Assessment of Protective Finishing Systems for Magnesium

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# ASSESSMENT OF PROTECTIVE FINISHING SYSTEMS FOR MAGNESIUM

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## Abstract

Improved corrosion-preventive finishing systems that are environmentally compatible are needed for magnesium gearboxes in the helicopter industry. This paper assesses the corrosion resistance of several protective finishing systems for ZE41A-T5 and QE22A-T6 magnesium alloys. The systems incorporated Dow 17 anodize, HAE anodize, and TAGNITE anodic electrodeposition, with and without sealant, primer, and polyurethane topcoat. The tests employed included 5 percent salt spray, wet adhesion of organic coatings, fatigue, abrasion resistance, and impact resistance. The TAGNITE coatings on both alloys produced corrosion resistance superior to the Dow 17 and HAE coatings. The best results were obtained from finishing systems that used TAGNITE as the initial treatment. TAGNITE sealed with three coats of Rockhard resin and overpainted with epoxy polyamide primer and polyurethane topcoat produced the best combination of all properties. The TAGNITE coating compared favorably to the other anodized coatings for wet organic coating adhesion, fatigue, abrasion resistance, and impact resistance.

## 1. Introduction

Improvements in helicopter performance by the use of lightweight magnesium have been offset by corrosion problems, resulting in increased maintenance and reduced readiness. Helicopter parts historically made from magnesium are being replaced with aluminum, even though there is a weight penalty. For the helicopter industry to regain confidence in magnesium, more corrosion-resistant alloys and improved protective finishing systems are needed. Also, these systems must conform to strict environmental regulations controlling emissions and the use of hazardous materials.

The foundation of all protective finishing systems is the surface treatment. Both chemical and electrochemical methods are used for modification of magnesium surfaces. The commonly used chemical methods (e.g., Dow 1, Dow 7, Dow 19, and chrome manganese) are environmentally hazardous since they contain chromates. Of the common electrochemical methods, HAE is environmentally compatible and Dow 17, a chromic acid anodic treatment, is not. These anodic and chemical conversion coatings provide an effective paint base, but offer little corrosion protection.[1]

This paper compares a new, chromate-free, anodic electrodeposition surface treatment called TAGNITE, developed by Technology Applications Group, Inc., of Grand Forks, North Dakota, to the standard HAE and Dow 17 processes. For touch-up, brush TAGNITE and Dow 19 treatments were compared. Complete protective finishing systems using surface sealing, chromated and non-chromated compliant primers, and a polyurethane topcoat were also evaluated. Evaluations were conducted on magnesium alloys ZE41A-T5 and QE22A-T6, which are currently used on both military and commercial helicopter gearboxes.

## 2. Materials

The materials and processes evaluated are shown in Figure 1. Test variables included (a) magnesium alloy; (b) initial conversion coating and thickness; (c) type, presence, and number of coats of sealant; (d) type and presence of primer; and (e) presence of topcoat. Various combinations of the variables were evaluated to represent different areas on helicopter gearboxes. For example, environmentally exposed external surfaces may receive a conversion coating, sealant, primer and topcoat; internal surfaces may require a conversion coating and sealant; and faying surfaces may only tolerate a conversion coating and thin coat of primer.

| FINISHING SYSTEM | VARIABLES |
|---|---|
| TOPCOAT | MIL-C-46168 |
| PRIMER | MIL-P-23377,TYPE I, CLASS 3<br>PR330 |
| SEALANT | ROCKHARD RESIN<br>MIL-R-3043 RESIN |
| CONVERSION COATING | DOW 17, HAE, DOW 19<br>TAGNITE: 8200, 8500 & BRUSH |
| MAGNESIUM SUBSTRATE | ZE41A-T5 ALLOY<br>QE22A-T6 ALLOY |

Fig. 1 Combination of Materials and Processes Used to Create Different Protective Finishing Systems.

### 2.1 Magnesium Alloys

Table I contains the chemical composition of the two sand-cast magnesium alloys used in this evaluation: ZE41A-T5 and QE22A-T6 alloys.

TABLE I. CHEMICAL COMPOSITION

| Alloy | Alloying Elements (wt.%) | | | | | |
|---|---|---|---|---|---|---|
| | Zn | Zr | Ag | *RE | Ni | Cu |
| ZE41A-T5 | 4.6 | 0.8 | 0.05 | 1.35 | <0.005 | 0.01 |
| QE22A-T6 | 0.04 | 0.7 | 2.4 | 2.11 | <0.005 | 0.01 |

* Rare Earths

2.2 Conversion Coatings

HAE, Dow 17, TAGNITE 8200 and 8500,[2] and Dow 19 conversion coatings were applied in accordance with Table II. Light (thin) and heavy (thick) conversion coatings were evaluated. TAGNITE 8200 and 8500 coatings were evaluated on the QE22A-T6 alloy; however, only the TAGNITE 8200 coating was evaluated on the ZE41A-T5 alloy. Panels coated with HAE, which were not resin sealed, were given a bifluoride-dichromate post-treatment.

TABLE II. CONVERSION COATINGS

| Name | Specification | Bath Solution | Type | Coating Thickness (μm) |
|---|---|---|---|---|
| HAE | MIL-M-45202 | Hydroxide Fluoride Phosphate Manganate | IA-Light IIA-Heavy | 2.5-7.6 33-43 |
| Dow 17 | MIL-M-45202 | Phosphate Fluoride Chromate | IC-Light IID-Heavy | 2.5-12.7 23-41 |
| TAGNITE 8200 | *None | Hydroxide Silicate Fluoride | I-Light II-Heavy | 5.1-10.2 20-25 |
| TAGNITE 8500 | *None | Hydroxide Silicate Fluoride Vanadate | I-Light II-Heavy | 5.1-10.2 20-25 |
| Dow 19 | MIL-M-3171 | Chromic Acid | VI | Neglig. |
| Brush TAGNITE | *None | Fluoride Hydroxide Silicate | None | 5.1 Max. |

* TAGNITE was applied in accordance with an internal specification of Technology Applications Group, Inc.

2.3 Organic Coatings

The material specification, material type, volatile organic compounds (VOC) content, and applied coating thicknesses for the sealants,[3,4] primers,[5,6] and topcoat[7] are presented in Table III.

The MIL-P-23377 primer, PR330 primer, and MIL-C-464168 topcoat were sprayed in accordance with standard industry practice. The MIL-P-23377 primer was cured for 1 hour at 49°C. The PR330 primer was cured at ambient temperature. The Rockhard resin was applied by spraying in accordance with the procedure in Table IV. When only one coat of Rockhard resin was required, curing was at 165°C for 4 hours. The MIL-R-3043 resin was sprayed, air-dried for 1 hour at room temperature, and then cured at 163°C for 30 minutes.

TABLE III. ORGANIC COATINGS

| Name | Specification | Type | VOC (g/l) | Coating Thickness (μm) |
|---|---|---|---|---|
| Rockhard Resin | DTD 5562 (British) | Epoxy Phenolic (Thinner) | 625 (883) | 1 coat: 12-20 3 coats:28-46 |
| Resin | MIL-R-3043 | Phenol Formaldehyde | 700 Max. | 34-45 |
| PR330 Primer | None | Epoxy Chromate-Free | 347 Max. | No Topcoat: 30-43 |
| Primer | MIL-P-23377 Type I, Class 3 | Epoxy Polyamide Strontium Chromate | 340 Max. | No Topcoat: 12-20 Yes Topcoat: 30-53 |
| Topcoat | MIL-C-46168 Type IV | CARC Polyurethane Chromate-Free | 420 Max. | 30-50 |

TABLE IV. APPLICATION OF ROCKHARD RESIN

| | |
|---|---|
| 1. | Pre-Heat to 165°C for 15 Minutes |
| 2. | Cool to 60°C |
| 3. | Spray with First Coat of Resin |
| 4. | Partial Cure at 165°C for 20 Minutes |
| 5. | Cool to 60°C |
| 6. | Spray with Second Coat of Resin |
| 7. | Partial Cure at 165°C for 20 Minutes |
| 8. | Cool to 60°C |
| 9. | Spray with Third Coat of Resin |
| 10. | Final Cure at 165°C for 180 Minutes |

3. Test Procedures

The testing program included 5 percent salt spray resistance, wet adhesion of organic coatings, wear resistance, impact resistance, fatigue properties, and coating morphology analysis. Each protective finishing system was not evaluated by every test.

3.1 Corrosion Resistance

Panels used in the corrosion resistance tests were approximately 100 by 150 by 6 mm. One-half of each panel had a machined surface, while the other half exhibited an as-cast surface. The racking hole was always located on the as-cast surface. Both cast and machined surfaces were scribed with an "X" per ASTM D 1654 after application of the finishing system.

Finished panels were exposed to salt spray in accordance with ASTM B 117 for periods up to 42 days, and periodically evaluated in accordance with ASTM D 1654, Procedure A. Mean migration from the scribe was measured, as well as the percentage of the unscribed area which failed. On a rating scale of zero to ten, ten is best and zero is worst.

3.2 Wet Adhesion

Wet adhesion of organic coatings was evaluated on a machined surface. The finished panels were immersed in deionized water at 49°C for 4 days prior to adhesion testing. Adhesion was measured by the crosscut tape test in accordance with ASTM D 3359, Method B.

### 3.3 Wear Resistance

A Taber abraser was used to compare the wear resistance of Dow 17, HAE, and TAGNITE surface treatments on the ZE41A-T5 alloy. Tests were conducted in duplicate in accordance with ASTM D 4060. The surface coatings were abraded by CS-17 wheels under an applied load of 1,000 grams. The Taber wear index, which is the weight loss in milligrams per thousand cycles, was calculated for each coating.

### 3.4 Impact Resistance

A Gardner impact tester was used on the ZE41A-T5 alloy to compare the impact resistance of surface treatments with and without sealant. Testing was conducted in accordance with ASTM D 2794. A 900-gram weight with a 12.7-mm diameter indentor impacted the panels. Adhesion of the finishing system in the impacted area was evaluated using the ASTM D 1654 tape test. The height of the weight was increased until the point of cracking, crazing, or loss of adhesion of the finishing system. The gram-meters at the impact failure end point was determined for each finishing system.

### 3.5 Fatigue

Rotating beam fatigue tests were used to determine the effect of surface treatment on fatigue properties of cast magnesium alloys. At least twelve specimens were utilized to generate each S/N curve. Cyclic frequency was about 6,000 rpm, and runout was ten million cycles. Specimens were (a) cut from cast plate, (b) machined to an hourglass configuration, (c) polished longitudinally with #600 SiC paper, and (d) randomized before surface treatment to avoid progressive deviations associated with casting the material. Test bars from both alloys were treated with heavy TAGNITE and heavy Dow 17.

## 4. Results

### 4.1 Salt Spray Resistance

#### 4.1.1 Finishing Systems for Gearbox Internal Surfaces

Variables in protective finishing systems, for use primarily on gearbox internal surfaces, were type of conversion coating, thickness of the TAGNITE coatings, type of sealant, and presence and number of coats of Rockhard resin. The finishing systems applied to the ZE41A-T5 alloy are ranked in Figure 2, based on corrosion migration from the scribe in the machined surface. The appearance of the ZE41A-T5 panels after 14 days of 5 percent salt spray exposure is presented in Figure 3. Finishing systems applied to the QE22A-T6 alloy are ranked in Figure 4, based on corrosion migration from the scribe. TAGNITE 8200 and 8500 coatings on the QE22A-T6 alloy are compared in Figure 5 after 28 days of 5 percent salt spray exposure.

Cast surfaces (those with a racking hole) were generally more susceptible to corrosion than the machined surfaces. Alloy QE22A-T6 generally exhibited more corroded surface area in the unscribed regions than the ZE41A-T5 alloy. Mean migration from the scribe was longer for the ZE41A-T5 alloy than the QE22A-T6 alloy.

The light TAGNITE 8200 coating had significantly better salt spray resistance in the scribed and unscribed areas than the light HAE and Dow 17 coatings on both ZE41A-T5 and QE22A-T6 alloys. The TAGNITE 8500 coating had significantly better salt spray resistance than the TAGNITE 8200 coating on the QE22A-T6 alloy. Heavy TAGNITE coatings protected both alloys against salt spray corrosion significantly better than light TAGNITE coatings.

Corrosion protection of both alloys was enhanced by surface sealing the conversion coatings. Three coats of Rockhard resin were significantly better than one coat. The light HAE coating showed a greater change in corrosion resistance than the light TAGNITE 8200 coating when sealed with Rockhard resin.

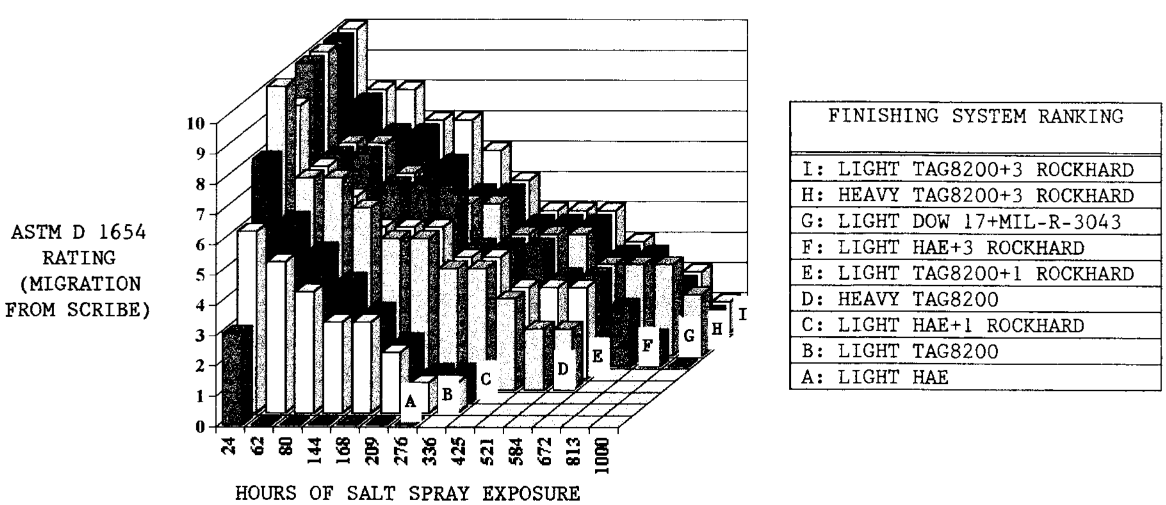
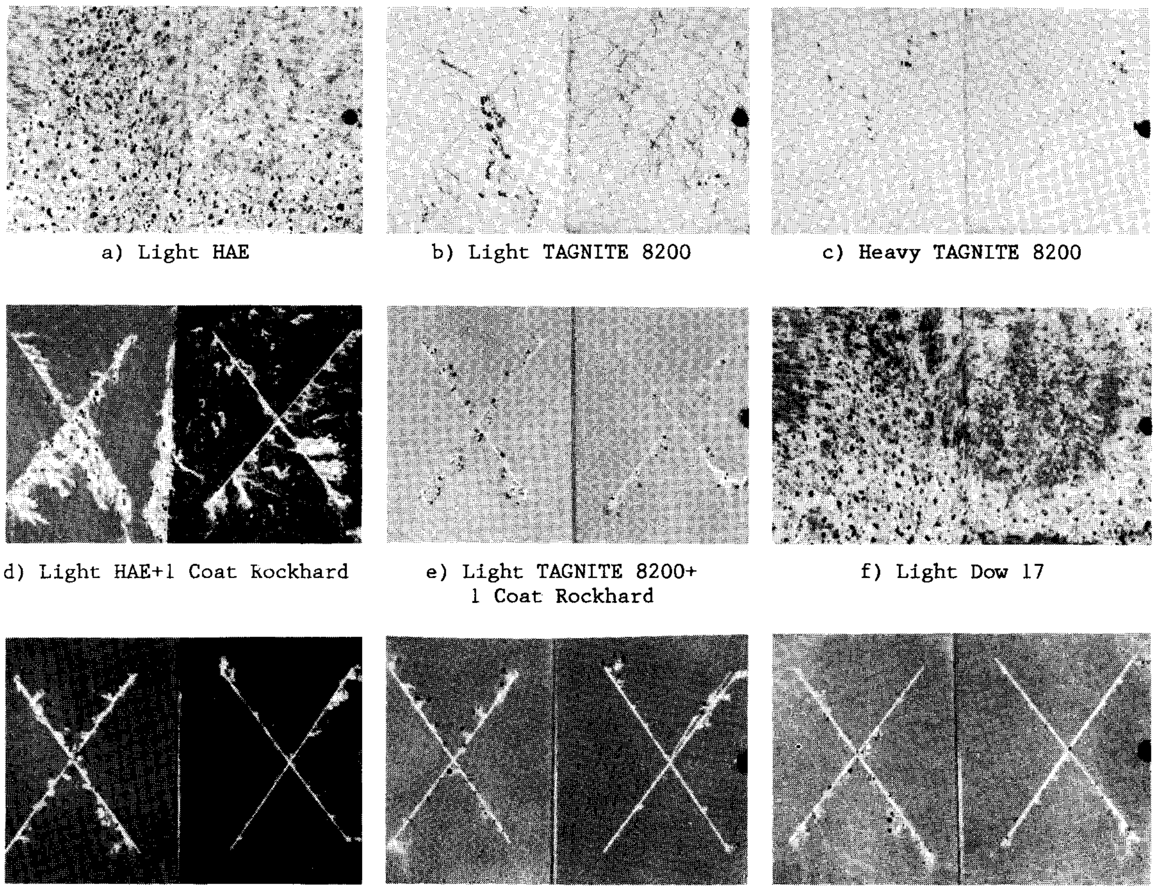



Fig. 2 Comparison of Conversion Coating and Sealant Combinations on ZE41A-T5 Alloy Exposed to 5 Percent Salt Spray. Systems Shown in Increasing Order of Resistance to Corrosion Migration.

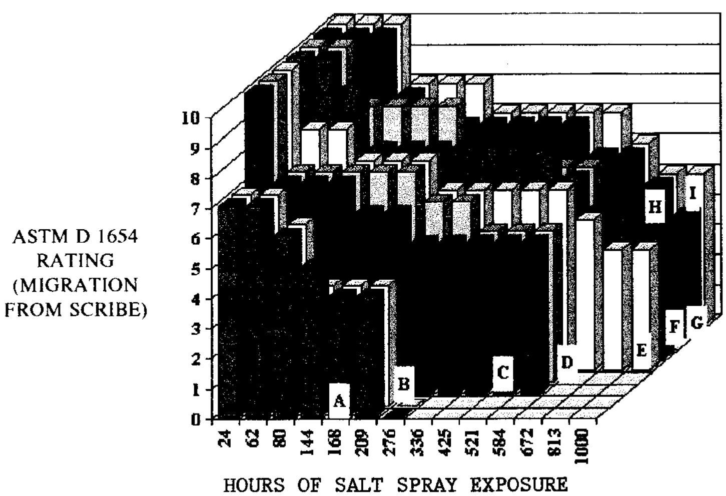


a) Light HAE b) Light TAGNITE 8200 c) Heavy TAGNITE 8200

d) Light HAE+1 Coat Rockhard e) Light TAGNITE 8200+ 1 Coat Rockhard f) Light Dow 17

g) Light HAE+3 Coats Rockhard h) Light TAGNITE 8200+ 3 Coats Rockhard i) Heavy TAGNITE 8200+ 3 Coats Rockhard

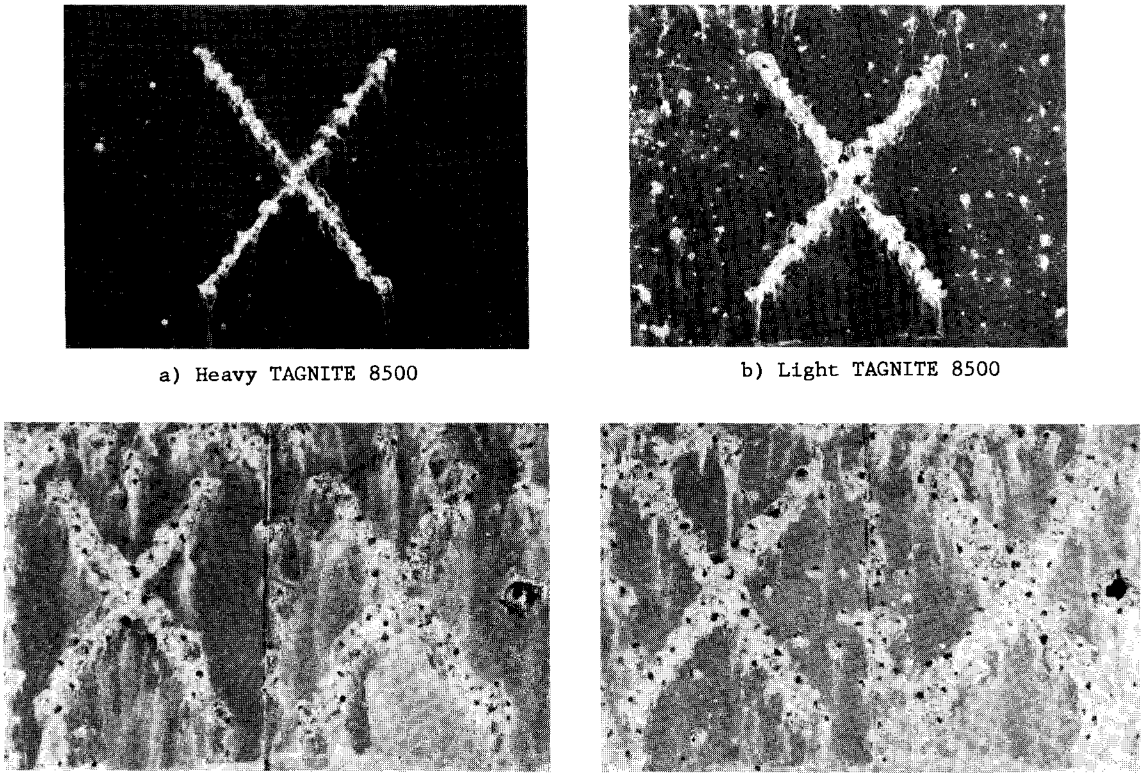
Fig. 3 Appearance of Conversion Coating and Sealant Combinations on ZE41A-T5 Alloy After 14 Days of 5 Percent Salt Spray Exposure.




| FINISHING SYSTEM RANKING |
|---|
| I: HEAVY TAG8200+3 ROCKHARD |
| H: HEAVY TAG8500 |
| G: LIGHT TAG8500 |
| F: LIGHT TAG8200+3 ROCKHARD |
| E: LIGHT HAE+3 ROCKHARD |
| D: HEAVY TAG8200 |
| C: LIGHT TAG8200 |
| B: LIGHT HAE |
| A: LIGHT DOW 17 |

Fig. 4 Comparison of Conversion Coating and Sealant Combinations on QE22A-T6 Alloy Exposed to 5 Percent Salt Spray. Systems Shown in Increasing Order of Resistance to Corrosion Migration.

However, when sealed with an equivalent number of coats, the light and heavy TAGNITE coatings exhibited better salt spray resistance than the light HAE coating. Performance of the light Dow 17 coating sealed with MIL-R-3043 resin was approximately equivalent to the light HAE coatings sealed with three coats of Rockhard resin.



a) Heavy TAGNITE 8500

b) Light TAGNITE 8500

c) Heavy TAGNITE 8200

d) Light TAGNITE 8200

Fig. 5 Appearance of TAGNITE 8200 and 8500 Coatings on QE22A-T6 Alloy After 28 Days of 5 Percent Salt Spray Exposure.

Unsealed, heavy TAGNITE coatings protected the magnesium better than light HAE coatings sealed with one coat of Rockhard resin. Also, the unsealed heavy TAGNITE 8500 coating prevented corrosion of the QE22A-T6 alloy better than the light HAE coating sealed with three coats of Rockhard resin. When surface sealed with three coats of Rockhard resin, the heavy TAGNITE 8200 treatment produced slightly better overall corrosion protection in comparison to the light TAGNITE 8200 treatment.

4.1.2 Protective Finishing Systems for Faying Surfaces

Variables in protective finishing systems, for use primarily on gearbox faying surfaces and butt joints, were the type of conversion coating and primer. Finishing systems applied to the ZE41A-T5 and QE22A-T6 alloys are ranked in Figure 6, based on corrosion migration from the scribe in the machined surface. The appearance of ZE41A-T5 panels after 14 days of 5 percent salt spray exposure is presented in Figure 7. As shown, MIL-P-23377 primer was significantly more effective in preventing salt spray corrosion when both alloys were treated with light TAGNITE rather than light HAE or light Dow 17. Additionally, for the QE22A-T6 alloy, MIL-P-23377 primer was more effective on the light TAGNITE 8500 coating than the light TAGNITE 8200 coating.

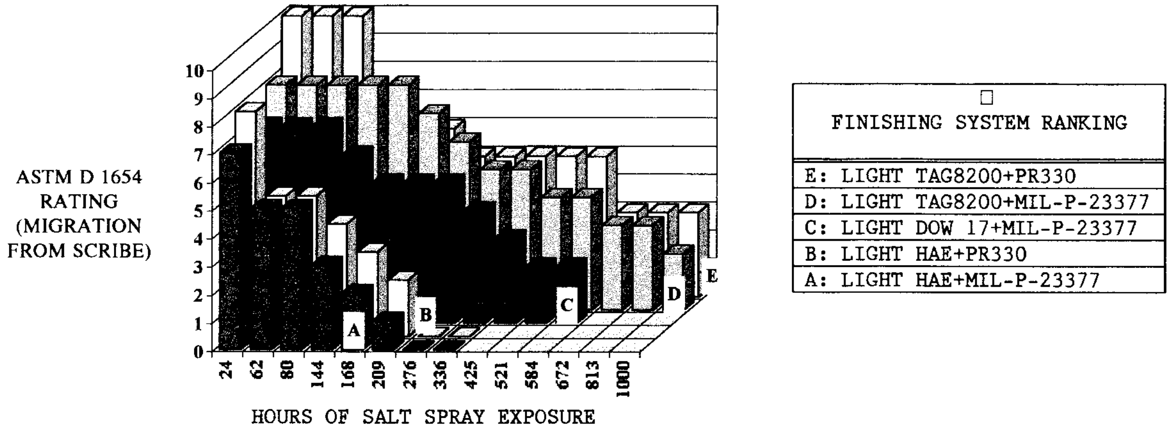
MIL-P-23377 and PR330 primers were compared on the light HAE and light TAGNITE 8200 coatings. On both coatings, the performance of the PR330 primer, which is chromate free, was equivalent to or better than that of MIL-P-23377 primer, which contains chromates. The PR330 primer was approximately two times thicker than the MIL-P-23377 primer, which partly contributed to the excellent performance when compared to MIL-P-23377 primer.

A comparison of Figures 2 and 4 to Figure 6 shows the light TAGNITE coatings overpainted with MIL-P-23377 and PR330 primers exhibited approximately equivalent or less corrosion migration from the scribe than light TAGNITE coatings sealed with three coats of Rockhard resin.

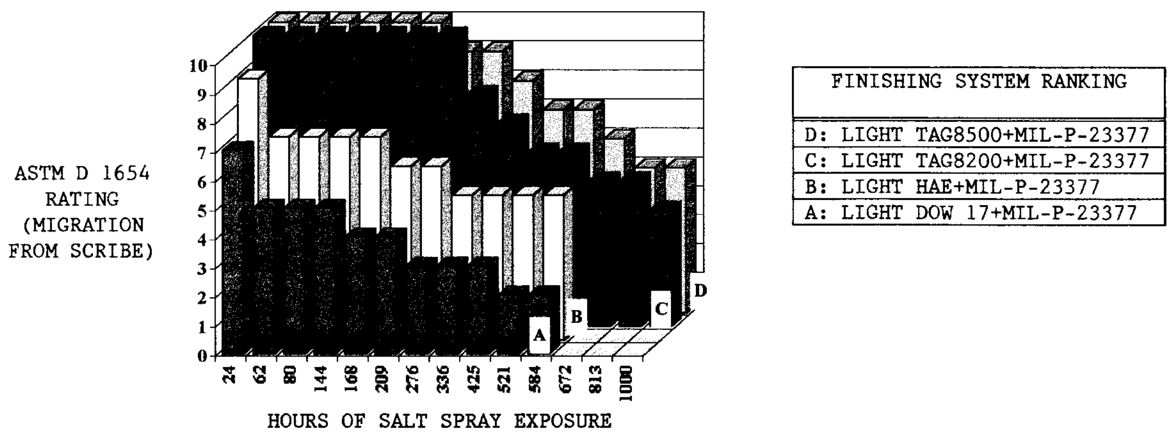
4.1.3 Protective Systems for External Surfaces

Variables in protective finishing systems, for use on external gearbox surfaces, were the type of conversion coating, thickness of the TAGNITE coatings, and presence of three coats of Rockhard resin. The epoxy polyamide primer (MIL-P-23377) and polyurethane topcoat (MIL-C-46168) were constants. The finishing systems applied to the ZE41A-T5 and QE22A-T6 alloys are ranked in Figure 8, based on corrosion migration from the scribe in the machined surface. The appearance of the QE22A-T6 panels after approximately 6 weeks of 5 percent salt spray exposure is presented in Figure 9.

Substituting light TAGNITE 8200 coating for light Dow 17 coating significantly improved the performance of the epoxy polyamide primer and polyurethane topcoat finishing system for both alloys. Corrosion protection of QE22A-T6 alloy was further enhanced when the light TAGNITE 8200 coating was replaced with the heavy TAGNITE 8500 coating. Full finishing systems using unsealed TAGNITE coatings had equivalent or better corrosion resistance than similar systems using the HAE coating sealed with three coats of Rockhard

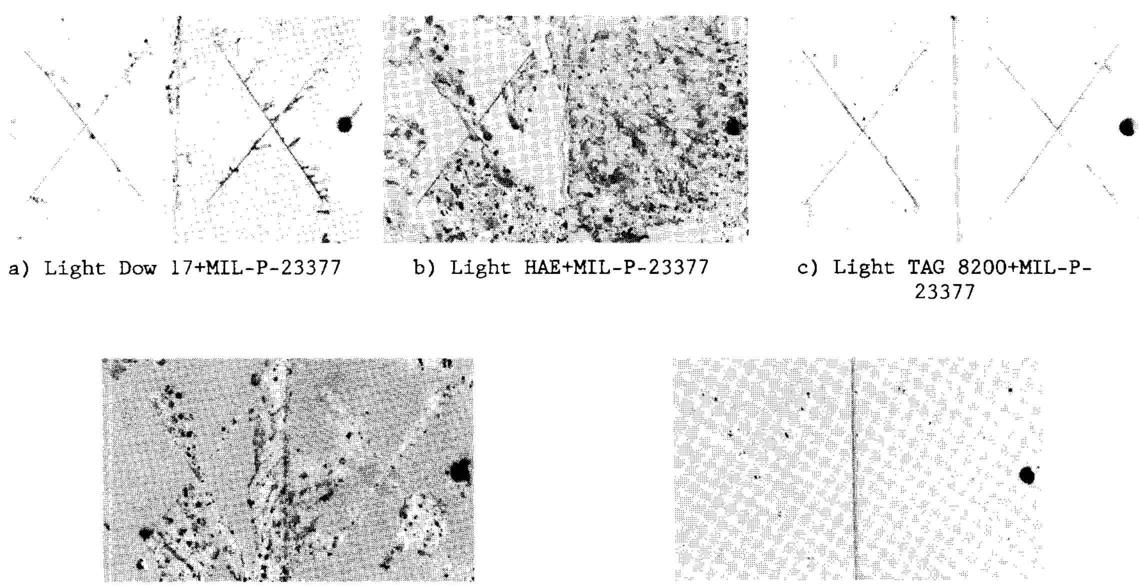



a) ZE41A-T5 Alloy




b) QE22A-T6 Alloy

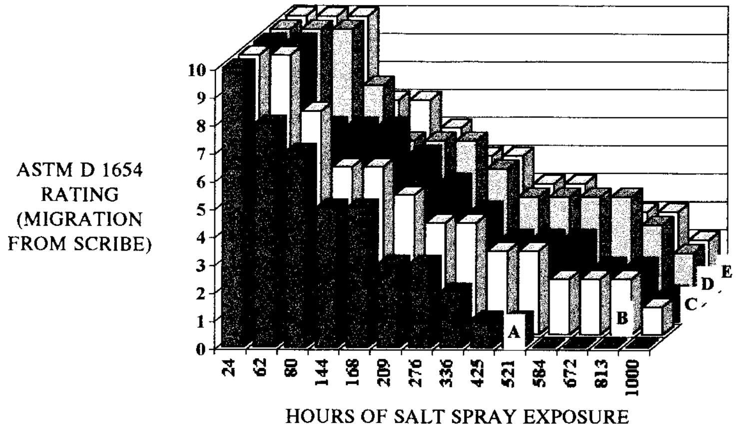
Fig. 6 Comparison of Conversion Coating and Primer Combinations Exposed to 5 Percent Salt Spray. Systems Shown in Increasing Order of Resistance to Corrosion Migration.



a) Light Dow 17+MIL-P-23377 b) Light HAE+MIL-P-23377 c) Light TAG 8200+MIL-P-23377

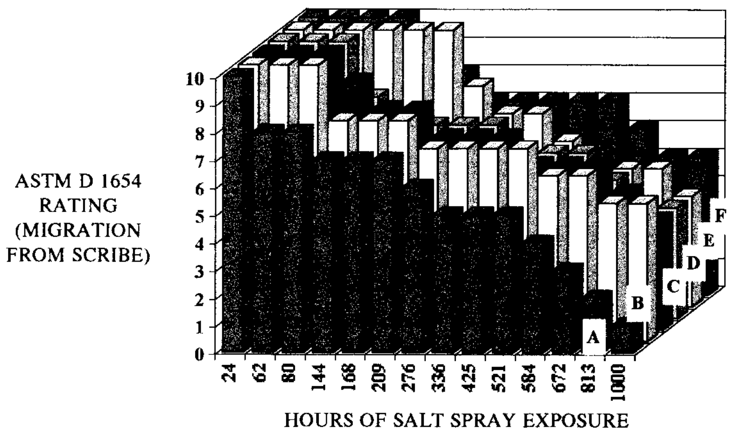
d) Light HAE+PR330 e) Light TAG 8200+PR330

Fig. 7 Appearance of Conversion Coating and Primer Combinations on ZE41A-T5 After 14 Days of 5 Percent Salt Spray Exposure.




| FINISHING SYSTEM RANKING |
|---|
| E: HEAVY TAG8200+3 ROCKHARD+ MIL-P-23377+MIL-C-46168 |
| D: LIGHT TAG8200+MIL-P-23377 +MIL-C-46168 |
| C: LIGHT TAG8200+3 ROCKHARD+ MIL-P-23377+MIL-C-46168 |
| B: LIGHT HAE+3 ROCKHARD+ MIL-P-23377+MIL-C-46168 |
| A: LIGHT DOW 17+MIL-P-23377+ MIL-C-46168 |

a) ZE41A-T5 Alloy



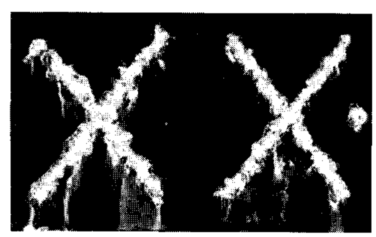

| FINISHING SYSTEM RANKING |
|---|
| F: HEAVY TAG8200+3 ROCKHARD+ MIL-P-23377+MIL-C-46168 |
| E: HEAVY TAG8500+MIL-P-23377 +MIL-C-46168 |
| D: LIGHT TAG8200+3 ROCKHARD+ MIL-P-23377+MIL-C-46168 |
| C: LIGHT TAG8200+MIL-P-23377 +MIL-C-46168 |
| B: LIGHT HAE+3 ROCKHARD+ MIL-P-23377+MIL-C-46168 |
| A: LIGHT DOW 17+MIL-P-23377+ MIL-C-46168 |

b) QE22A-T6 Alloy

Fig. 8 Comparison of Conversion Coating, Sealant, Primer and Topcoat Combinations Exposed to 5 Percent Salt Spray. Systems Shown in Increasing Order of Resistance to Corrosion Migration.

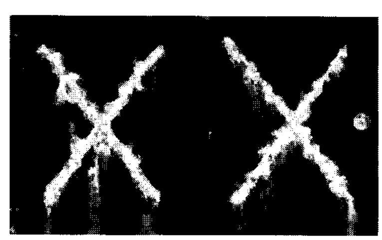
a) Light Dow 17+MIL-P-23377+
MIL-C-46168

b) Light HAE+3 Rockhard+
MIL-P-23377+MIL-C-46168



c) Light TAG 8200+
MIL-P-23377+MIL-C-46168

d) Light TAG 8200+3 Rockhard+
MIL-P-23377+MIL-C-46168



e) Heavy TAG 8200+3 Rockhard+
MIL-P-23377+MIL-C-46168

Fig. 9 Appearance of Conversion Coating, Sealant, Primer, and Topcoat Combinations on QE22A-T6 Alloy After 42 Days of 5 Percent Salt Spray Exposure.

resin. Sealing the light TAGNITE 8200 coating with three coats of Rockhard resin did not improve the performance of unsealed, full finishing systems on either alloy. However, improved corrosion resistance was obtained by sealing the heavy TAGNITE 8200 coating on the QE22A-T6 alloy.

## 4.2 Coating Adhesion

The coating adhesion of several finishing systems after immersion in deionized water at 49°C for 4 days is shown in Table V for the ZE41A-T5 alloy. Similar results were obtained for the QE22A-T6 alloy.

TABLE V. RESULTS OF THE TAPE ADHESION TEST

| Finishing System | *ASTM D 3359 Rating |
|---|---|
| Light HAE+Rockhard | 4B |
| Light TAG 8200+Rockhard | 4B |
| Light Dow 17+MIL-R-3043 | 1B |
| Light HAE+MIL-P-23377 | 3B |
| Light TAG 8200+MIL-P-23377 | 3B |
| Light Dow 17+MIL-P-23377 | 3B |
| Light TAG 8200+PR330 | 2B |
| Light HAE+Rockhard+MIL-P-23377+MIL-C-46168 | 5B |
| Light TAG 8200+Rockhard+MIL-P-23377+MIL-C-46168 | 5B |

* 5B is best and 0B is worst.

Adhesion of the MIL-P-23377 primer to each conversion coating was approximately the same. Failure typically occurred at the interface between the conversion coating and the magnesium. The PR330 primer did not adhere as well as the MIL-P-23377 primer to the conversion coatings. Failure occurred at the interface between the PR330 primer and conversion coating. Despite a low adhesion rating, the PR330 primer performed well in salt spray tests.

Adherence of MIL-P-23377 primer to the Rockhard resin was very good. Coating systems using Rockhard resin usually had better adherence than those without the sealant. Adhesion of Rockhard resin to TAGNITE 8200 and HAE coatings was significantly better than MIL-R-3043 resin to the Dow 17 coating.

Adhesion ratings of these finishing systems are lower than reported in the literature for similar systems.[8,9] This may be due, in part, to (a) inspection of the cross-cut area at magnifications up to 40X rather than the standard 10X, and (b) inclusion in the loss-of-adhesion calculations of the ridges formed on either side of the incisions by metal displaced from the blade.

## 4.3 Wear Resistance

Taber abrasion of electrochemical conversion coatings on the ZE41A-T5 alloy is compared in Figure 10. As shown, wear resistance of the light and heavy TAGNITE 8200 coatings was at least five times better than the light Dow 17 coating, and thirty-five times better than the very heavy HAE coating. The HAE coating was designated as "very heavy" because it was twice the maximum thickness specified for heavy HAE.

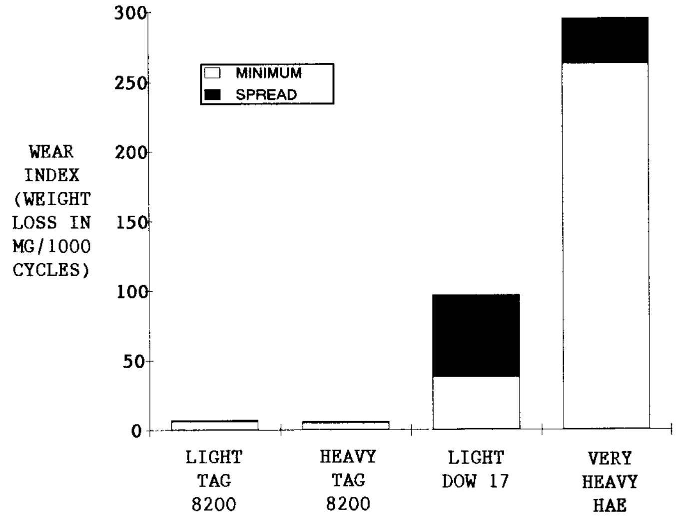



Fig. 10 Comparison of the Taber Abrasion Resistance (ASTM D 4060) of Electrochemical Conversion Coatings.

## 4.4 Impact Resistance

Impact resistance of the conversion coatings on the ZE41A-T5 alloy with and without Rockhard resin is compared in Figure 11. Impact resistance of the light and heavy TAGNITE 8200 coatings was slightly better than the light Dow 17 coating. Sealing the conversion coatings with three coats of Rockhard resin increased impact resistance at least fivefold.

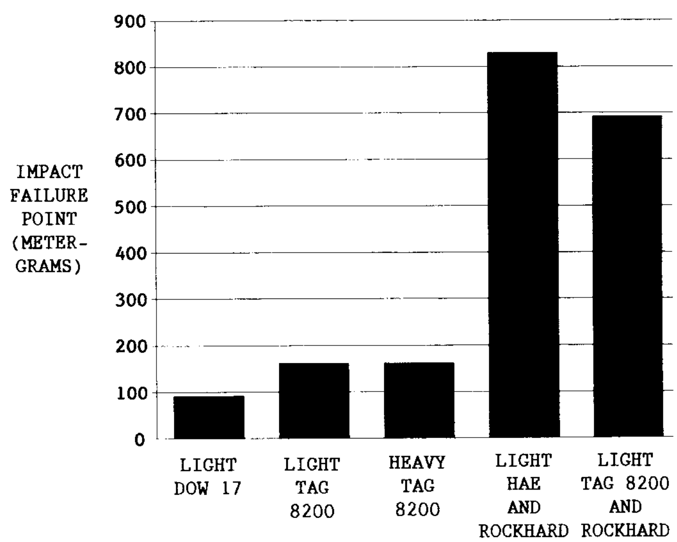



Fig. 11 Comparison of Impact Resistance (ASTM D 2794) of Sealed and Unsealed Conversion Coatings.

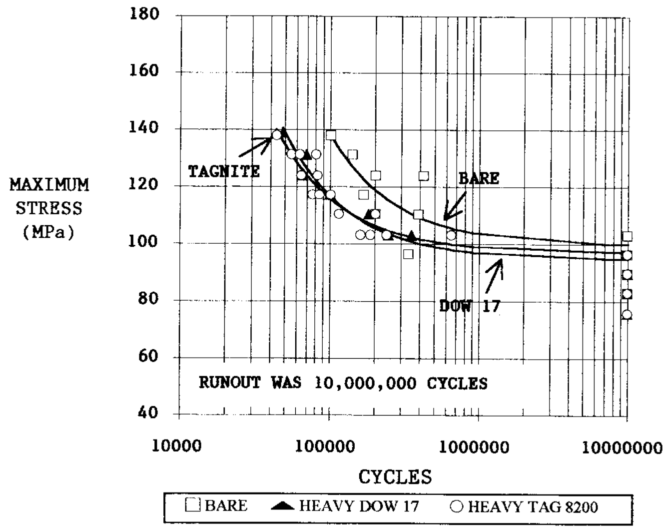
## 4.5 Fatigue

Table VI contains tensile properties of the magnesium sand castings used in this evaluation.

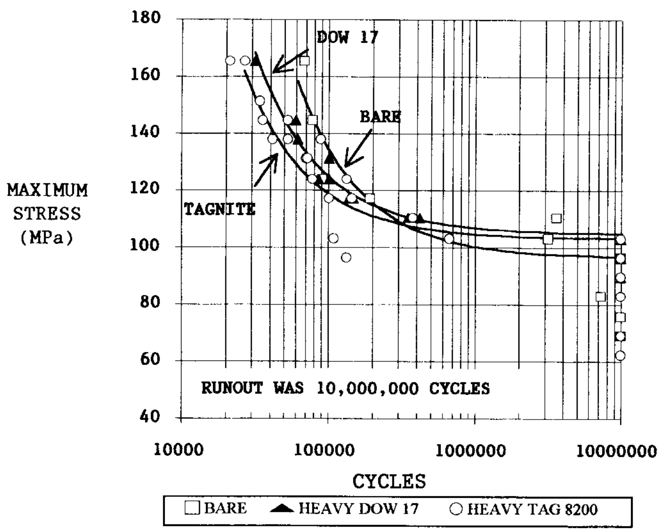
The S-N curves for the as-polished, heavy TAGNITE, and heavy Dow 17 treatments are plotted in Figure 12 for ZE41A-T5 and QE22A-T6 alloys. On the ZE41A-T5 alloy, there was no significant difference between the

TABLE VI. TENSILE PROPERTIES

| Alloy | Tensile Strength (MPa) | Yield Strength (MPa) | Elongation (Percent) |
|---|---|---|---|
| ZE41A-T5 | 218 | 150 | 5 |
| QE22A-T6 | 280 | 215 | 7 |




a) ZE41A-T5




b) QE22A-T6

Fig. 12 Rotating Beam Fatigue Curves for As-Polished, Heavy Dow 17, and Heavy TAGNITE Surface Treatments.

heavy Dow 17 and heavy TAGNITE surface treatments. At high cycles, there was no significant reduction in fatigue life compared to the as-polished finish. At low cycles, both treatments showed a 15 percent reduction in fatigue strength compared to the as-polished finish.

For QE22A-T6 alloy, the heavy Dow 17 and heavy TAGNITE surface treatment showed no reduction in fatigue strength at high cycles compared to the as-polished finish. However, at low cycles the heavy TAGNITE treatment showed a 12 percent reduction in fatigue strength, compared to 7 percent for the heavy Dow 17 treatment.

4.6 Surface Morphology

Top surface morphologies of Dow 17, HAE, and TAGNITE 8200 coatings are compared in Figure 13. Pores in the TAGNITE 8200 coating, which were 1 to 5 microns across, were significantly smaller and more uniform in size and distribution than those in the Dow 17 coating, which were 5 to 50 microns across, and those in the HAE coating, which were 5 to 40 microns across.

Cross sections through the conversion coatings are shown in Figure 14. TAGNITE 8200 coating contained significantly fewer interconnecting pores that penetrated through to the magnesium substrate. The Dow 17 coating contained the deepest and most interconnected porosity.

A comparison of coating morphologies explains why the TAGNITE coating was a significantly more effective corrosion barrier than Dow 17 and HAE coatings. Pores in the TAGNITE 8200 coating are smaller and more uniform in size and distribution, with less interconnection than those in the other anodized coatings. Consequently, there are fewer paths in the TAGNITE coating for the corrosive environment to reach the magnesium substrate. D. Bartak reported similar results.[10]

4.7 Touch-Up

The Dow 19 treatment was compared to brush TAGNITE for touch-up use on the ZE41A-T5 alloy. Photographs of panels coated with Dow 19 on one half and brush TAGNITE 8200 on the other half are shown in Figure 15 after 11 days of 5 percent salt spray exposure. The brush TAGNITE coating showed a marked improvement over the Dow 19 coating.

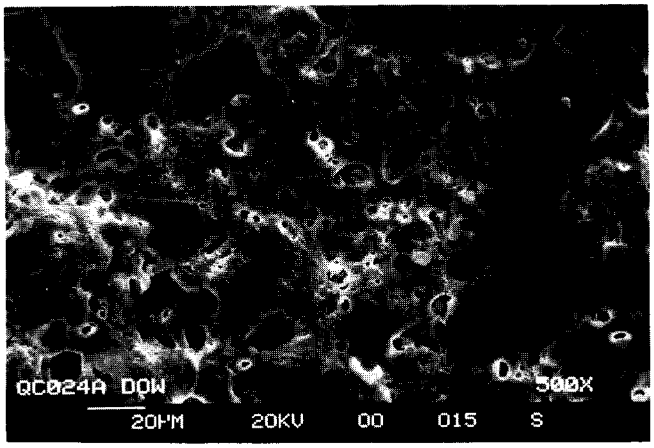
Corrosion initiated in the area treated with Dow 19 in less than 24 hours, compared to 80 hours for that coated with brush TAGNITE. Corrosion initiation was delayed in excess of 2 weeks when brush TAGNITE was overpainted with MIL-P-23377 primer. The primer did not significantly delay corrosion initiation in the area treated with Dow 19.

4.8 Application

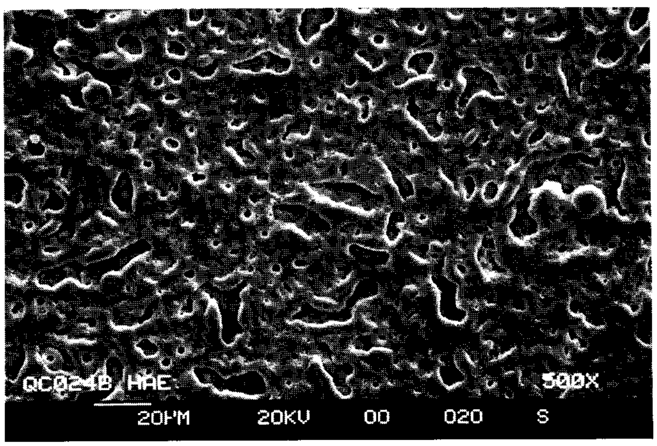
TAGNITE 8200 and 8500 coatings were applied to the helicopter gearbox components. Analysis of the boxes showed that TAGNITE successfully coated the internal passages and blind holes. Gearbox components coated with TAGNITE 8200 are shown in Figure 16.

5. Discussion

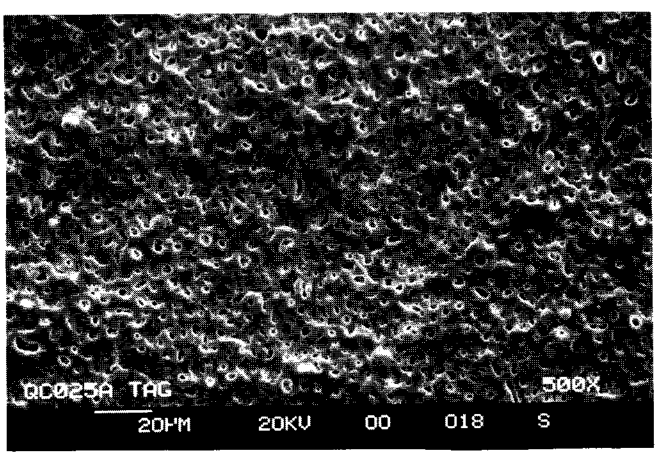
TAGNITE 8200 and 8500 coatings had significantly better abrasion resistance than HAE and Dow 17 coatings. Also, TAGNITE coatings compared favorably to the other anodized films for wet paint adhesion, impact resistance, and fatigue properties. However, the most significant advantage of the TAGNITE coatings was resistance to salt spray corrosion. On the QE22A-T6 alloy, the TAGNITE 8500 coating had better salt spray resistance than the TAGNITE 8200 coating.




a) Light Dow 17 Coating

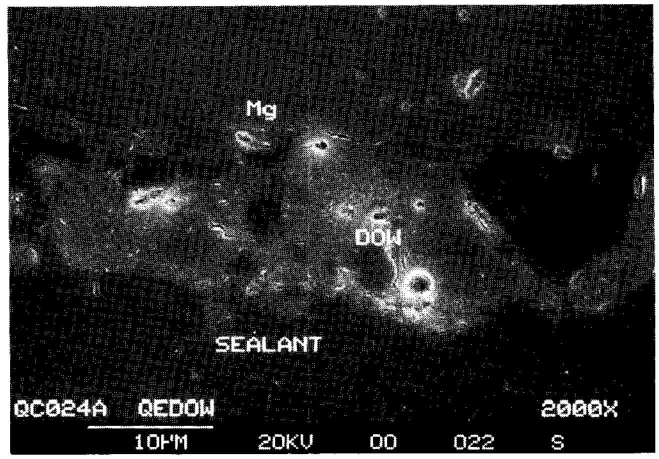



b) Light HAE Coating

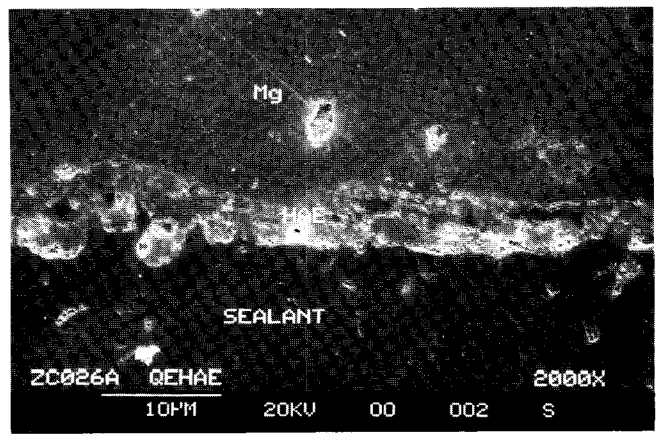



c) Light TAGNITE 8200 Coating

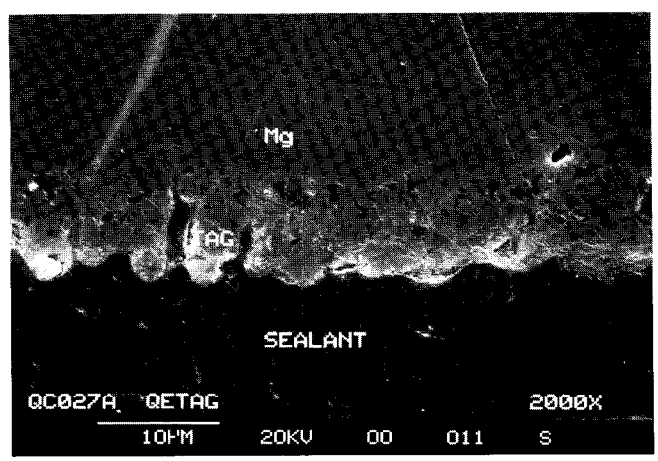
Fig. 13 Scanning Electron Photomicrographs of a Top View of Conversion Coatings on QE22A-T6 Alloy. (500X)




a) Light Dow 17 Coating




b) Light HAE Coating

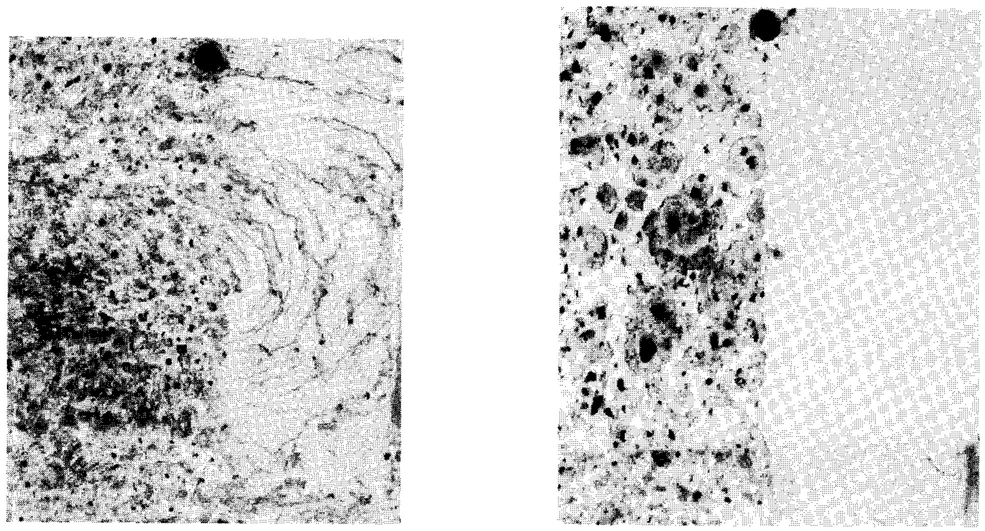



c) Light TAGNITE 8200 Coating

Fig. 14 Scanning Electron Photomicrographs of Cross Sections Through Conversion Coatings on QE22A-T6 Alloy. (2000X)

Only the TAGNITE 8200 coating was evaluated on the ZE41A-T5 alloy.

Dow 17, HAE, and TAGNITE coatings were all good paint bases. However, unlike Dow 17 and HAE anodized coatings, TAGNITE anodic electrodeposition coatings provided significant corrosion protection without additional organic finishes. Consequently, TAGNITE coatings have a large advantage in corrosion protection over the other anodic coatings in fine tolerance areas such as liner bores and faying surfaces, where organic finishes are prohibited or must be very thin.



a) Dow 19 (Left)
b) Brush TAGNITE 8200 (Right)

c) Dow 19+MIL-P-23377 (Left)
d) Brush TAGNITE 8200+MIL-P-23377 (Right)

Fig. 15 Photographs Comparing Dow 19 and Brush TAGNITE Coatings After 11 Days of 5 Percent Salt Spray Exposure.

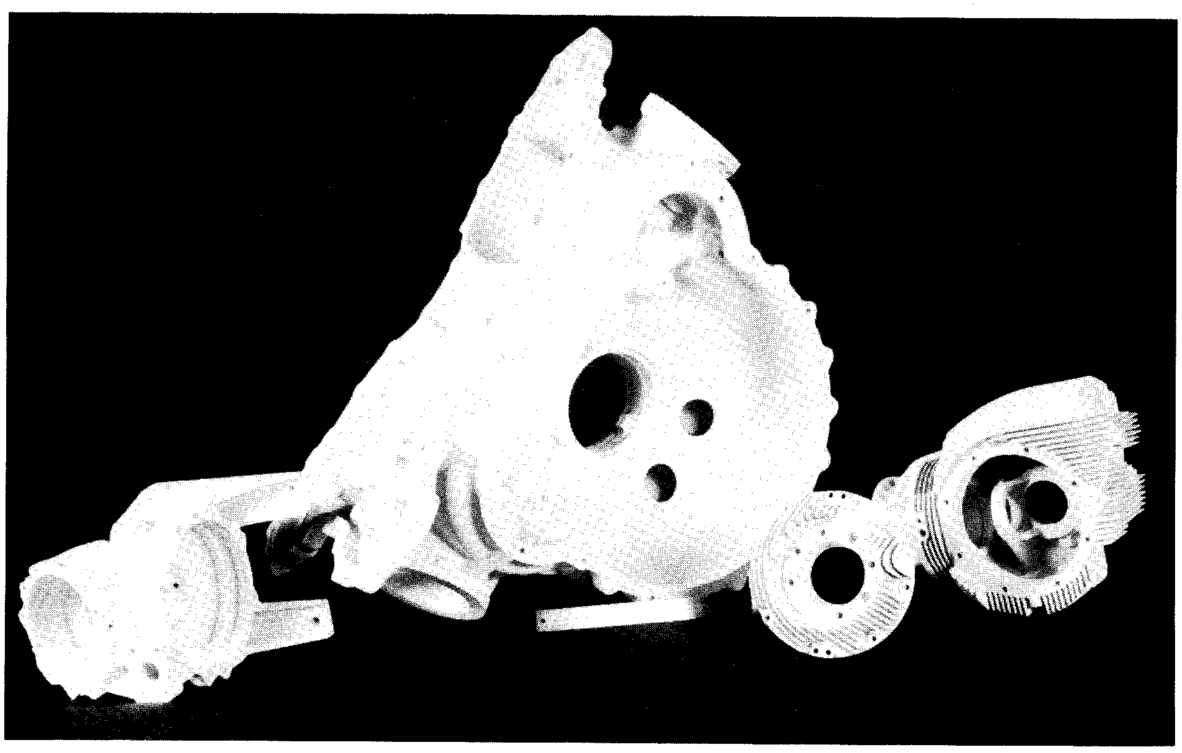


Fig. 16 Magnesium Gearbox Components Treated with TAGNITE.

The response to surface sealing of the TAGNITE 8200 anodic electrodeposition coating was similar to that previously reported[11] for chrome-manganese, Dow 17, and HAE conversion coatings. Surface sealing the TAGNITE 8200 coating with Rockhard resin significantly improved corrosion resistance. Also, corrosion protection improved with increasing the number of coats of surface sealant. Although surface sealing significantly narrowed the gap in corrosion performance between TAGNITE and HAE coatings, protective finishing systems using the sealed TAGNITE 8200 coating were superior to systems using the sealed HAE coating. Optimum corrosion resistance was obtained from the thick TAGNITE coatings; however, the advantage of thick coatings over thin coatings was also narrowed by surface sealing.

When overpainted with primer, the TAGNITE 8200 and 8500 anodic electrodeposition coatings produced a different response than the HAE and Dow 17 anodized coatings. Overpainting the TAGNITE coatings with MIL-P-23377 primer was as effective in reducing salt spray corrosion migration as surface sealing the TAGNITE coating with three coats of Rockhard resin. This finding was contrary to the behavior observed for the HAE and Dow 17 anodic coatings and the findings reported by Tawil,[1] in which surface sealing was much more effective than overpainting. At twice the thickness of the MIL-P-23377 primer, PR330 primer (which does not contain chromates) was as effective in preventing corrosion as the chromate-containing MIL-P-23377 primer.

Interposing three coats of Rockhard resin between the TAGNITE anodic electrodeposition coating and MIL-P-23377 primer did not markedly improve corrosion performance of the polyurethane MIL-C-46168 topcoat. This behavior was contrary to that of full finishing systems using conventional conversion coatings. Levy et al.[9] reported that when using HAE and chrome-manganese surface treatments, sealing the conversion coatings significantly improved the salt spray resistance of the full system.

The Rockhard resin, a British-manufactured sealant, was effective in sealing pores in the HAE and TAGNITE conversion coatings. Finishing systems using the HAE and TAGNITE coatings sealed with Rockhard resin had equivalent or better corrosion resistance and superior wet adhesion than systems using the Dow 17 coating sealed with MIL-R-3043 resin, a United States-manufactured sealant. However, VOC content of both the Rockhard (resin: 625 g/l; thinner: 883 g/l) and MIL-R-3043 (700 maximum g/l) resins exceeds the VOC limit established by Rule 1124 of the South Coast Air Quality Management District).[12] Although not specifically designated in Rule 1124, surface sealants should fall between 350 g/l for primers and 600 g/l for sealants. A VOC-compliant resin is needed to produce a truly environmentally compatible protective finishing system for magnesium.

Steel bearing liners and other hardware are often installed in helicopter gearboxes during machining to maintain tolerances when a gearbox distorts from the relaxation of residual stresses. Touch-up solutions (e.g., Dow 19) and baths, (e.g., Dow 7 and chrome-manganese) in which components containing hardware may be safely immersed, are not environmentally compatible since they contain chromates. With appropriate masking, the brush TAGNITE treatment should be an environmentally acceptable alternative to these processes. Since the chrome-manganese, Dow 7, and Dow 19 processes result in negligible metal loss, a dimensional increase of up to 5 microns of TAGNITE must be offset.

Many magnesium components on helicopters are treated with Dow 17 and are not surface sealed. Switching to the TAGNITE coating instead of the HAE coating will eliminate chromates, and will also provide a substantial improvement in corrosion protection. Although the TAGNITE coatings provide corrosion protection and overpainting with MIL-P-23377 primer is nearly as effective in preventing corrosion as surface sealing, internal and external gearbox surfaces treated with TAGNITE should still be sealed to obtain the fivefold improvement in impact resistance.

## 6. Conclusions

HAE and TAGNITE coatings are both environmentally acceptable alternatives to the Dow 17 coating, which contains chromates. When protective and functional requirements for gearbox liner bores and internal, external, and faying surfaces are considered collectively, TAGNITE coatings were superior to the HAE coating. The TAGNITE 8500 coating was more effective in reducing corrosion than the TAGNITE 8200 coating on the QE22A-T6 alloy. Surface sealing TAGNITE coatings with three coats of Rockhard resin provided the best combination of impact resistance and corrosion protection. The brush TAGNITE process is a viable replacement for the Dow 19 touch-up treatment. The TAGNITE coatings compared favorably to the other anodized films for wet paint adhesion, impact resistance, abrasion resistance, and fatigue properties.

## Acknowledgments

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