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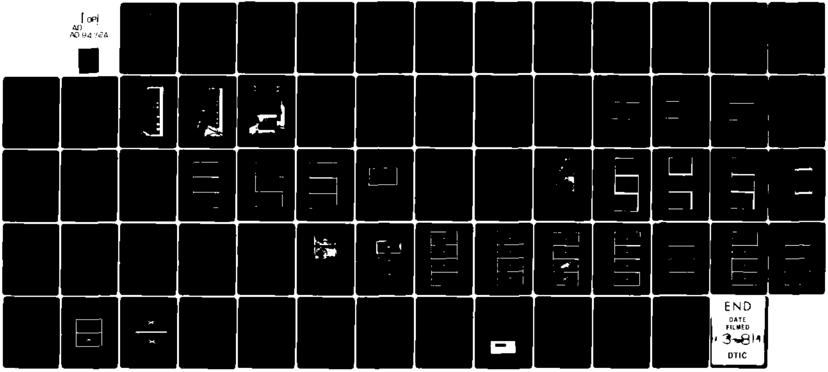

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EVALUATION OF POWDER COATINGS FOR APPLICATION TO AIRCRAFT COMPONENT PARTS

Everett Charves
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

4 September 1980

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AIRTASK NO. WR02206001
Work Unit JP203

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Powder coatings, electrostatically applied to bare and primed aluminum and magnesium substrates, were evaluated as possible candidate coatings for aircraft and engine component parts. The powdered coatings were compared to the solvent based MIL-P-23377 primer and MIL-C-81773 topcoat system.

When selected for specific applications, powdered coatings were superior to the solvent based coatings system in abrasion (wear) and chemical resistance.

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SUMMARY

INTRODUCTION

This project was authorized by the Naval Air Systems Command, Washington, D. C. under Air Task WR02206001, Work Unit JP203. The purpose of the project was to investigate the properties of electrostatically applied powder coatings to bare as well as primed aluminum and magnesium alloy substrates, and to compare them to the chemical and physical properties of the conventionally sprayed solvent based coating system currently utilized as the protective exterior finish on naval aircraft.

The selected powder coatings were subjected to abrasion, adhesion, chemical resistance, corrosion, strippability and low temperature flexibility tests. Hot engine and hydraulic oil tests, and moisture (humidity cabinet) studies, also were conducted.

The coating evaluations were based on standard tests to which solvent based coatings are subjected prior to their acceptance for use on naval weapons systems.

SUMMARY OF RESULTS

Powdered coatings were successfully applied to bare and to primed aluminum and magnesium substrates utilizing the electrostatic application process. Good adhesion was obtained using selected military specification primers and proprietary primers that were comparable to powdered coatings applied directly to the unprimed (bare) substrates.

The powdered coatings, when applied over selected primers, exhibited good acid resistance properties. Optimum alkali resistance properties were obtained when applying the powdered topcoats over chromate inhibited MIL-P-23377 primed panels. Topcoated test panels primed with the proprietary primers that did not contain chromates were not as resistant to alkalis.

The low temperature flexibility test illustrated that the flexible properties of the powdered coatings, were not affected by the use of a primer undercoat. The impact values were comparable to the MIL-C-81773 coating system, except for nylon, which was outstanding in flexible properties.

When subjected to the humidity chamber test, most of the applied powdered topcoats, with and without a primer undercoat, exhibited good adhesion properties. The vinyl topcoat, however, failed, except when applied over the MIL-P-23377 epoxy primer. The MIL-C-81773 coating system also met the necessary requirements.

The utilization of a chromate inhibited primer increased the corrosion resistance properties of epoxy powdered topcoats when subjected to the $NaCl-SO_2$ test. Intercoat failures, however, were experienced when a proprietary primer and two-component epoxy polyamide primers were utilized as the primer finishes for the low-temperature cure (LT) epoxy powdered topcoat.

No failures were experienced with the high-temperature cure (HT) epoxy powdered topcoats.

For hot oil resistance properties, the utilization of a primer finish did not affect the properties of the applied powdered coatings.

For abrasion resistance properties, the nylon and polypropylene powdered coatings exhibited excellent wear resistant properties, far exceeding the properties of a solvent based coating system such as MIL-C-81773.

Except for vinyl and cellulose acetate butyrate coatings, the strippability of powdered coatings, with and without a primer coat, can be troublesome. The coatings are difficult to remove using the specification MIL-R-81294 stripper currently being utilized to remove the standard MIL-C-81773 solvent based coating system.

Table I is a summary of the results of the physical tests performed on the tested powder coatings over primer MIL-P-23377D. The results of MIL-C-81773C over MIL-P-23377D (the standard Navy aircraft paint system) are also included. This is a preliminary guide for possible users of powder coatings.

Powder coatings have a 95 to 99% transfer efficiency (i.e., amount of coating material actually transferred to the substrate). Electrostatic application of these coatings enables wrap-around assuring good edge coverage. Powder coatings also have good self-leveling properties to provide a uniform finish.

Powder coatings are excellent for automatic and repetitive processes, being economical and convenient. Also, with no solvents present in these coatings and the high transfer efficiency they provide, the amount of toxic materials dispersed in the atmosphere is reduced to a minimum, reducing health hazards.

CONCLUSIONS

The overall chemical and physical properties of the thermoplastic and thermosetting powdered coatings, in most cases, were not significantly outstanding when compared to the solvent based MIL-P-23377 epoxy primer and MIL-C-81773 urethane topcoat paint system currently being applied to the exterior surfaces of naval attack and fighter aircraft. However, when specifically selected for a particular custom application, powdered coatings did exhibit superior properties to those of solvent based coatings, especially for wear and chemical resistance.

The advantages of using a primer coat are the increased corrosion protective and chemical resistance properties derived from a two-coat system. The primer coat, particularly the chromate inhibitive type, prevented or delayed corrosion when the topcoat became damaged or permeated by gaseous or liquid corrosive active compounds.

A disadvantage of utilizing a solvent based primer prior to electrostatically applying the powdered topcoat is that the solvent release or two-component crosslinking chromate inhibitive type primers must be allowed to set (dry hard) before topcoating. When applied over uncured or tacky primers, the chromate pigments migrate into the powdered coating, resulting in a discolored topcoat finish. This phenomenon is significant with white powdered topcoat finishes.

When properly selected for a particular application, electrostatically applied powder coatings can exhibit excellent corrosion, chemical, flexible and wear-resistant properties, thereby extending the service life of the aircraft or engine component part.

Powder coatings may also add convenience and cost savings to coating processes.

RECOMMENDATIONS

It is recommended that:

- powdered coatings should be carefully selected before being indiscriminately substituted for a solvent based coating system;

- powdered coatings be applied over a chromate inhibited primer to increase their chemical and corrosion properties;

- the primer coat be allowed to set (dry hard) before applying the powdered topcoat to prevent migration of the primer pigments into the applied topcoat;

- the removability (strippability) of the coating be taken into consideration before selecting a powdered coating for use on weapons systems, as powdered coatings can be difficult to remove from aircraft or engine component parts that require stripping prior to rework and overhaul.

TABLE I. POWDER COATINGS TESTS RESULTS

	(A)	(B)	(C)	(D)	(E)			(F)	(G)	(H)
					FLUID RESISTANCE					
Coating (All Tested over MIL-P-23377D)	Adhesion	Acid Resistance	Alkali Resistance	Flexibility	MIL-L-23699	MIL-H-23282	Skydrol 500	Abrasion Resistance	Strippability	Humidity Resistance
Cellulose Acetate Butyrate	Fail	E	E	F	Fail	Pass	Fail	G	Pass	Fail
Epoxy	Pass	E	E	G	Pass	Pass	Fail	F	Pass	Pass
Epoxy	Pass	E	E	G	Pass	Pass	Fail	G	Pass	Pass
Polyamide (Nylon)	Pass	E	E	E	Pass	Pass	Fail	E	Pass	Pass
Polyester	Pass	E	E	F	Pass	Pass	Fail	F	Fail	Pass
Polypropylene	Pass	E	E	P	Pass	Fail	Fail	E	Fail	Pass
Urethane	Pass	E	E	F	Fail	Pass	Fail	F	Fail	Pass
Vinyl	Pass	E	E	F	Fail	Pass	Fail	G	Pass	Pass
MIL-C-81773C	Pass	E	E	G	Pass	Pass	-	F	Pass	Pass

(A) Wet Tape Test, Federal Test Method Standard 141A, Method 6301.1
(B) 14 Day immersion in 29 degree baume' sulfuric acid
(C) 7 Day immersion in a 2N sodium hydroxide-aqueous solution
(D) G.E. Impact Test (based on percent elongation)
(E) 4 Hour immersion in fluid at 250°F (121°C)
(F) S.S. White Abrasive Test Unit; Federal Test Method Standard 141A, Method 6193
(G) Using MIL-R-81294
(H) 14 Days, 120°F (49°C) and 100% relative humidity

E - Excellent
G - Good
D - Fair
P - Poor

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BACKGROUND

Due to the changing technology in aircraft design and sophisticated mission capabilities, there is an increasing demand for organic protective coatings that exhibit increased temperature, abrasion, chemical and corrosion resistant properties. Most coatings presently utilized for protective purposes, are solvent release-room temperature cure-finishes. These finishes, which are chemically formulated for wet spray applications, have limited temperature abrasion, corrosion, chemical and weathering properties. The built-in fillers, extenders, plasticizers, solvents, etc. required to obtain stable, durable ready-to-use sprayable coatings are factors which place limits on their chemical and physical properties.

In contrast, powder coatings, when properly applied and cured, are reported to be homogeneous, coherent, durable and free from porosity as the coatings do not cure or dry hard by solvent evaporation.

When applying powder coatings electrostatically, it is possible to:

1. achieve a very highly efficient coating system using a powder coating booth to recover the overspray and
2. eliminate air and water pollution problems currently inherent with solvent based coating systems.

Therefore, to determine the advantage or disadvantages that electrostatically applied powder coatings may exhibit when compared to the conventionally applied solvent based coatings, this project was programmed into three major phases:

1. determination of the chemical and physical properties of powder coatings, both thermosetting and thermoplastic resins, when subjected to the environments in which naval aircraft operate
2. Testing and evaluation of selected primers as protective corrosion undercoats for both thermosetting and thermoplastic powder coatings, and
3. screening and selection of the most promising primer and powdered topcoats as candidate coatings for possible application to fixed and rotary wing aircraft and engine component parts.

COATING EQUIPMENT DATA

The powder coatings discussed in this report were applied to all test specimens using the electrostatic spraying technique. The equipment utilized was selected to take into consideration:

1. a method of delivering the powder from a suitable source to the object to be coated.

2. a method of applying a particle charge to the powder that is opposite to the object to be coated (ground).

3. maintaining the attractive charge so as to obtain adhesion (attraction) of the deposited particles to the coated substrate.

4. a method for fusing the powdered material so it will flow into a continuous adherent film-like coating.

5. an enclosed hood or spray booth to capture the oversprayed powder which does not become deposited and attracted to the object being coated (ground).

The apparatus meeting these requirements and utilized to electrostatically apply the selected powder coatings is shown in Figure 1.

Utilizing the Interrad/Gema Model 710 portable electrostatic unit, the powder dosage and the conveying air pressure could easily be adjusted to suit the particular object. The powder cloud was controlled using the application gun shown in Figure 2. By adjusting the deflector plate located at the tip of the gun, a narrow jet for recesses or a wide jet for flat objects can be obtained. The powder flow can also be adjusted in grams per minute for a specified gun using a powder rate flow diagram supplied by the equipment manufacturer.

The enclosed portable spray booth utilized with the Gema electrostatic spray unit is shown in Figure 3. The booth, also supplied by Gema, is designed to collect and recover any stray powder that has not been attracted and deposited to the grounded object. Sufficient air is exhausted to force the oversprayed and non-adherent powder into a separator and a resultant collection bin. The collected powder can then be reprocessed and reapplied electrostatically.

COATING APPLICATION DATA

APPLIED COATINGS

The selected powdered coatings were applied to bare and primed substrate test panels. The primer coatings selected for testing that meet military or federal specification requirements are the primers currently being utilized to protect naval aircraft and/or naval ships. Proprietary primers were included in the test program to keep abreast of newly developed products that are commercially available and may be superior to the currently used military specification coatings.

The types of powdered coatings included in the test program were selected based on the following criteria:

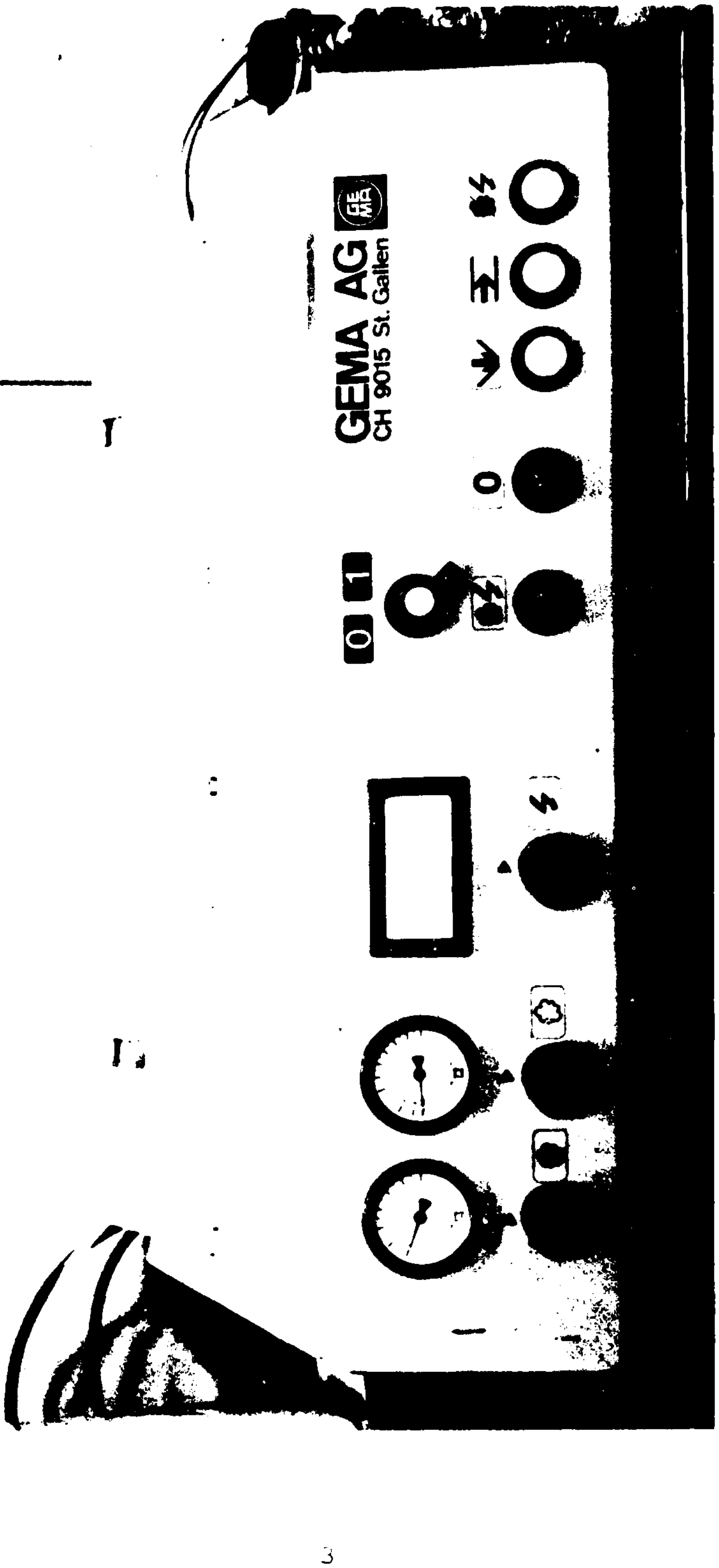


FIGURE 1. PORTABLE ELECTROSTATIC POWDER SPRAY UNIT

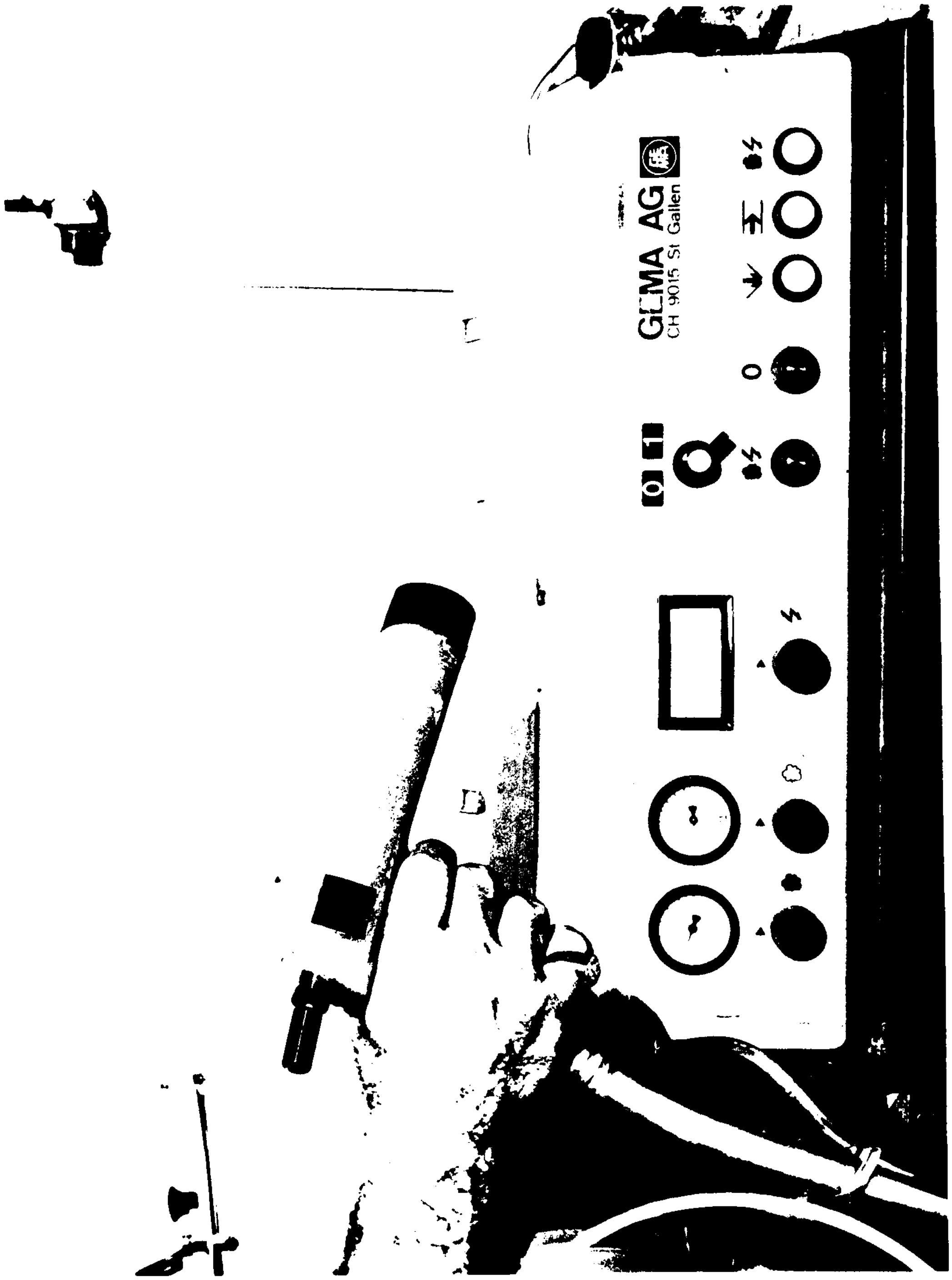


FIGURE 2. ELECTROSTATIC MANUAL SPRAY GUN

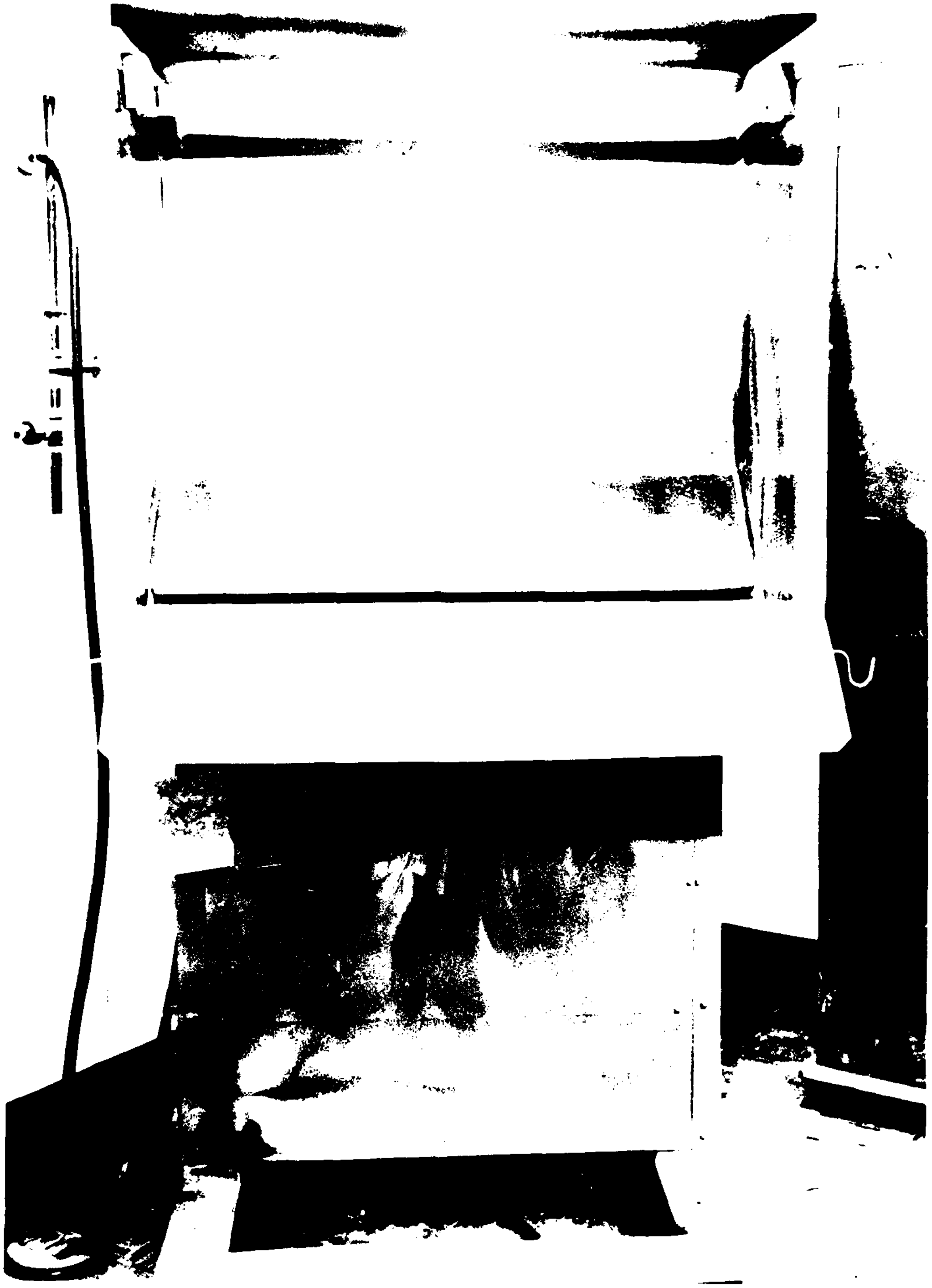


FIGURE 3. ENCLOSED PORTABLE SPRAY BOOTH

- to select a cross section of thermosetting and thermoplastic coatings most promising for naval weapons application.
- to correlate test data on powdered coatings that exhibit a chemical characteristic that is equivalent to currently utilized solvent based coatings, such as: solvent based urethane versus powder based urethane - solvent based epoxy coatings versus powdered based epoxy coating, etc.

The solvent based primer coatings and topcoat selected for testing are as follows:

MIL-P-23377C Epoxy Polyamide Primer Part I Base, Part II Catalyst (Mix 1:1).

MIL-P-24441 Epoxy Polyamide Primer Part I Base, Part II Catalyst (Mix 1:1).

Rilprim P-104 Primer
Part I Base, Part II Acid Catalyst (Mix 1:1).

Rilsan P Primer
1 - Component

Epoxy Polyamine Primer (FPA)
Part I Base, Part II Catalyst (Blend 1:1)

MIL-C-81773B Linear Polyurethane Topcoat
Part I Base, Part II Catalyst (Mix 1:1)

The thermosetting and thermoplastic powdered topcoats selected for testing are as follows:

Cellulose Acetate Butyrate Coating Tenite (CAB)

Chemical Resistant Epoxy Coating (HT) PE-1-7-3

Fast Cure Epoxy Coating (LT) PE-1-7-3

Polyamide (Nylon) Coating Duralon JE

Polyester Coating (PE), Coro-Clad 721-W-001

Polypropylene Coating (PP), Hercotuf 1098

Urethane Coating, Duro-Dex 9X-1018

Vinyl Coating, Dri-Dex 99X6004

SUBSTRATE TEST PANELS

Flat aluminum test panels measuring 3x6x0.020 in. (7.62x15.24x0.05 cm) were used for all of the coating tests with the exception of the NaCl - SO_2 exposure test, where magnesium alloy panels of the same dimension were utilized. The aluminum alloy test panels and the chemical conversion and electrolytic coating selectively applied are designated as follows:

Specification MIL-C-5541B, Class 1A treated 2024 bare aluminum.

Specification MIL-C-8625 Type II (Sulphuric acid anodized) 2024 O-temper aluminum alloy.

The aluminum alloys designated as 2024 bare meet Federal Specification QQ-A-250/4.

The magnesium alloy test panels were weldable grade AZ31B-H24 temper alloy meeting Federal Specification QQ-A-44a requirements.

APPLICATION OF COATINGS

The primer coatings were prepared for spray application as specified by the manufacturer and/or according to applicable military specification requirements. The coatings were spray applied using conventional equipment operating with an air pressure of 40 psi. All primer coats were applied to meet a dry film thickness of 0.6 mils (0.015 mm) to 0.8 mils (0.020 mm).

Utilizing standard coating procedures the primer coat is allowed to air dry approximately one hour before the solvent based topcoat is applied. This standard procedure could not be followed when topcoating solvent based primers with powdered coatings, especially the two-component amide and amine cured chromate inhibited epoxy primers. A minimum room temperature cure period of 24 hours or a one hour ambient dry period followed by two hours at 150°F (65.5°C) was necessary because:

- The two component solvent based epoxy primers, which cross-link through the use of a catalytic hardener (amide or amine), are not in a sufficiently cured and dry hard condition after a one hour air dry period prior to topcoating.

- When subsequently topcoated with the powdered topcoat and fused at temperatures ranging from 325 F (163 C) to 420 F (216 C), the retained high boiling solvents and fugitive pigments (chromates and coloring pigments) in the primer finish, bleed through the powder topcoat. This results in a discontinuous - discolored coating system. The discoloring phenomenon is especially prevalent when topcoating primed systems with white thermosetting and thermoplastic powdered topcoats.

The powdered topcoats were electrostatically applied to bare and primed test panels using the Interrad/Gema Model 710 portable electrostatic powder coating unit illustrated in Figure 1. The powdered coatings were applied in a film thickness range of 1.5 mils (0.038 mm) to 4.5 mils (0.114 mm), the film thickness being dependent upon the amount of powdered material required to achieve a satisfactory hiding coat.

FUSION TIME AND TEMPERATURES

Immediately following the electrostatic application of the powdered coatings to the bare and primed panels, they were subjected to specified oven temperatures suggested by the coatings manufacturer. An air circulating oven with a temperature range of 100°F (38°C) to 650°F (343°C) was utilized to fuse (cure) the powdered coatings. The temperature and time cure cycles utilized for each specific thermosetting and thermoplastic coating are presented in Table I-A.

TABLE I-A. FUSION (CURING) TEMPERATURE AND TIME DATA

Powder Coating	Color	Oven Temperature (°F)	(°C)	Time (Minutes)
Cellulose Acetate Butyrate (CAB)	Black	425 ± 5°F	218 ± 3°C	10
Epoxy (LT)	White	300 ± 5°F	148 ± 3°C	12
Epoxy (HT)	White	350 ± 5°F	176 ± 3°C	15
Polyamide (Nylon)	White	400 ± 5°F	204 ± 3°C	5
Polyester (PE)	White	400 ± 5°F	204 ± 3°C	10
Polyethylene (PN) Low Density	Natural (D)	250 ± 3°F	120 ± 3°C	5
Polyethylene (PN) High Density	Natural (D)	325 ± 5°F	162 ± 3°C	5
Polypropylene (PP)	Blue	400 ± 5°F(Q)	204 ± 3°C	7
Urethane (UR)	White	375 ± 5°F	190 ± 3°C	20
Vinyl (VL)	Green	400 ± 5°F	204 ± 3°C	5

(Q) - Quench in Cold Water after Fusion.

(D - Deleted as a Test Coating from Further Studies - Poor Adhesion.

TEST DATA

ADHESION (DRY AND WET) TEST

The selected powder topcoats, thermoplastic and thermosetting, were subjected to dry and wet adhesion tests. The coatings, with and without a primer coat, were applied to 2024 aluminum alclad test panels measuring 3x6x0.020 in. (7.62x15.24x0.51 cm). The aluminum test panels, prior to painting, were treated with a chemical conversion coating meeting MIL-C-5541, Class 1A requirements.

The dry adhesion tests were conducted by scribing two parallel lines, one inch (2.54 cm) apart and 1.5 inches (3.87 cm) long. Masking tape one inch long (2.54 cm) was then applied with the adhesive side down across the scribe marks and pressed securely against the surface of the coating. The tape was then removed with one quick motion and the coating examined for intercoat or coating to substrate failures.

The wet adhesion tests were conducted in the same manner except the test specimens were immersed in distilled water 24 hours prior to tape testing. The panels were then wiped dry, scribed and tested as previously described for the dry tape test. The wet tape test conforms to Federal Test Method Standard No. 141a, Method 6301.1. All of the coated test panels were allowed to condition at room temperature 48 hours prior to conducting the dry and wet adhesion tests.

As illustrated in Table II, all of the powder coatings, thermoplastics and thermosets when applied directly to the aluminum substrate, passed the dry and wet adhesion tests. Also passing, were the topcoats applied to primers designated Rilsan P, the one component epoxy-phenolic based primer, and primer MIL-P-24441. The only coating failures that occurred when using primers designated MIL-P-23377 and primer epoxy polyamine (EPA) were the small blisters that appeared on the cellulose acetate butyrate (CAB) topcoated panels. The blisters occurred during the 24 hour distilled water immersion test.

When utilizing Rilprim P-104 primer, three coating failures occurred when performing the wet adhesion test. The (CAB) topcoated panels experienced a severe intercoat adhesion failure mode, whereas the NYLON and the VINYL coated panels failed to the substrate (prior primer to substrate adhesion). Figures 4A and 4B illustrate six polyester coated test panels that passed the dry and wet adhesion tape test. All panels were primed, as designated, except for panel A. The top half of the panel was subjected to the dry (scribed) tape test, where as the lower half was subjected to the 24 hour wet (scribed) tape test. Figures 5A and 5B illustrate six nylon coated test panels also subjected to the dry and wet adhesion tests. Panel C failed to pass the wet tape test as illustrated by the lower half of the panel. The remaining panels (A, B, D, E, and F) passed the dry and wet adhesion tests.

The results of the adhesion tests performed on the low density and high density polyethylene powdered coatings were poor. As a result of their poor adherent properties, the polyethylene powder coatings were deleted from the testing program.

TABLE II. ANCHORAGE ADHESION TEST DATA

Applied Powdered Topcoat	Applied (Solvent Based) Primer Coats					
	Bare Substrate	Rilsan P	Rilprim P-104	MIL-P-24441	MIL-P-23377	Polyamine EPA
(CAB) Cellulose Acetate Butyrate	(P)	(P)	(P)	(P)	$(P)\cdot(F)_B$	$(P)\cdot(F)_B$
(LT) Epoxy	(P)	(P)	$(P)\cdot(F)_X$	(P)	(P)	(P)
(HT) Epoxy	(P)	(P)	(P)	(P)	(P)	(P)
Nylon (Clear)	(P)	(P)	$(P)\cdot(F)_X$	(P)	(P)	(P)
Nylon (Pigmented)	(P)	(P)	$(P)\cdot(F)_X$	(P)	(P)	(P)
(PE) Polyester	(P)	(P)	(P)	(P)	(P)	(P)
(PP) Polypropylene	(P)	(P)	(P)	(P)	(P)	(P)
(UR) Urethane	(P)	(P)	(P)	(P)	(P)	(P)
(VL) Vinyl	(P)	(P)	$(P)\cdot(F)_X$	(P)	(P)	(P)

Code:

(P) Pass dry tape test and wet tape test.

$(P)\cdot(F)_X$ -
(P) Pass dry tape test.
$(F)_X$ Failed wet tape test (Intercoat adhesion).

$(P)\cdot(F)_B$ -
(P) Pass dry tape test.
$(F)_B$ Failed wet tape test (Small coating blisters).

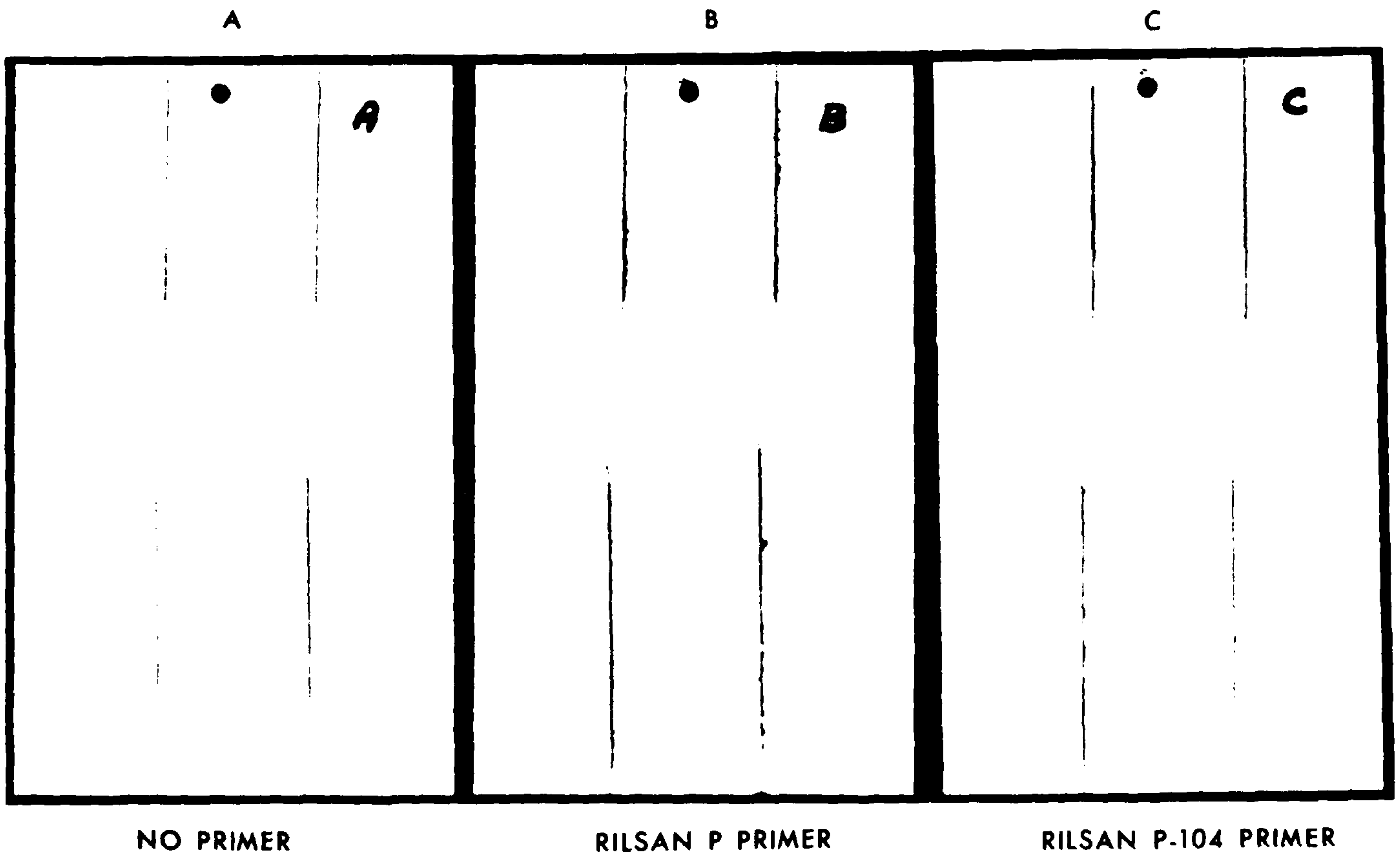


FIGURE 4A. WET AND DRY ADHESION TEST - POLYESTER TOPCOAT

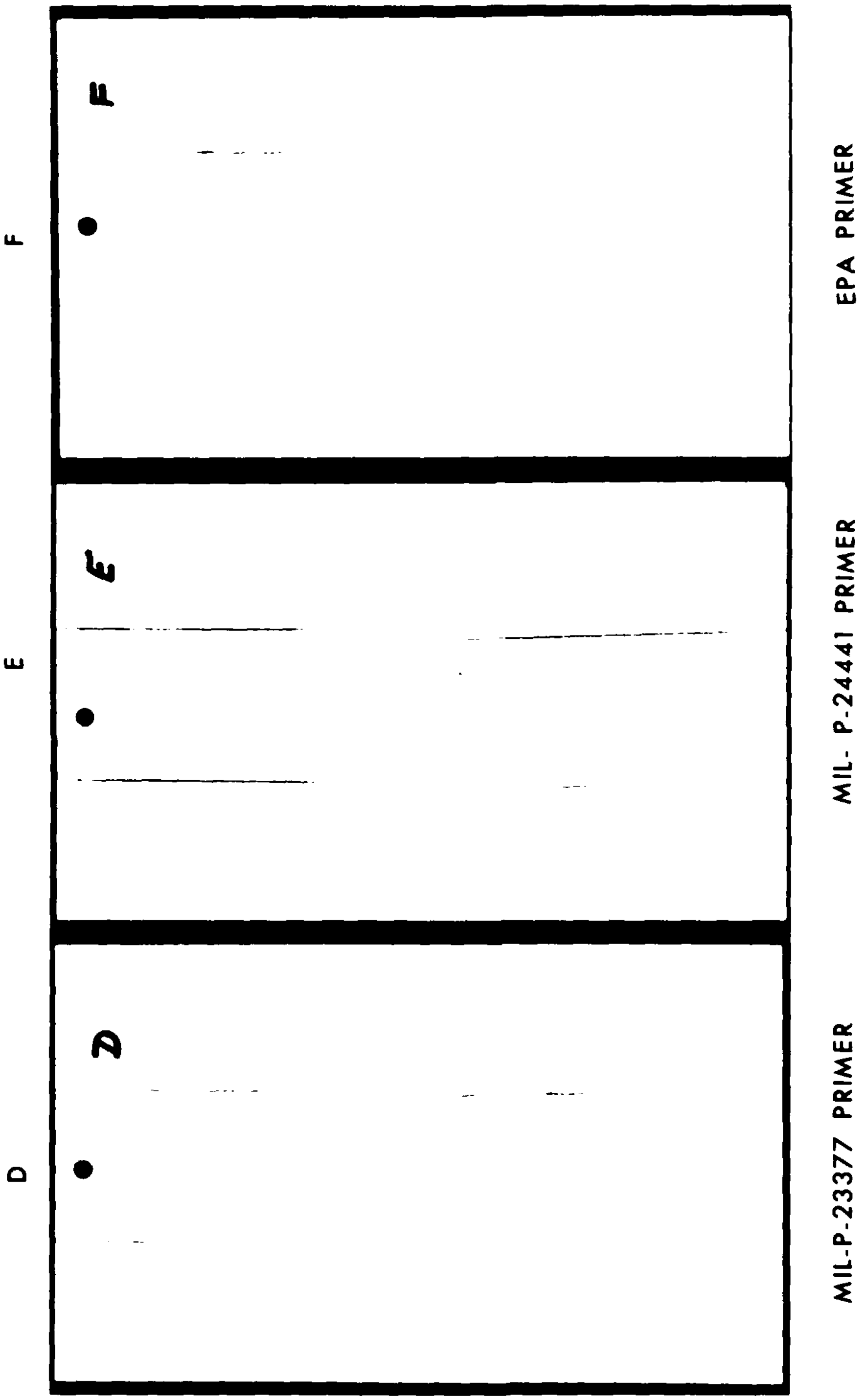


FIGURE 4B. WET AND DRY ADHESION TEST - POLYESTER TOPCOAT

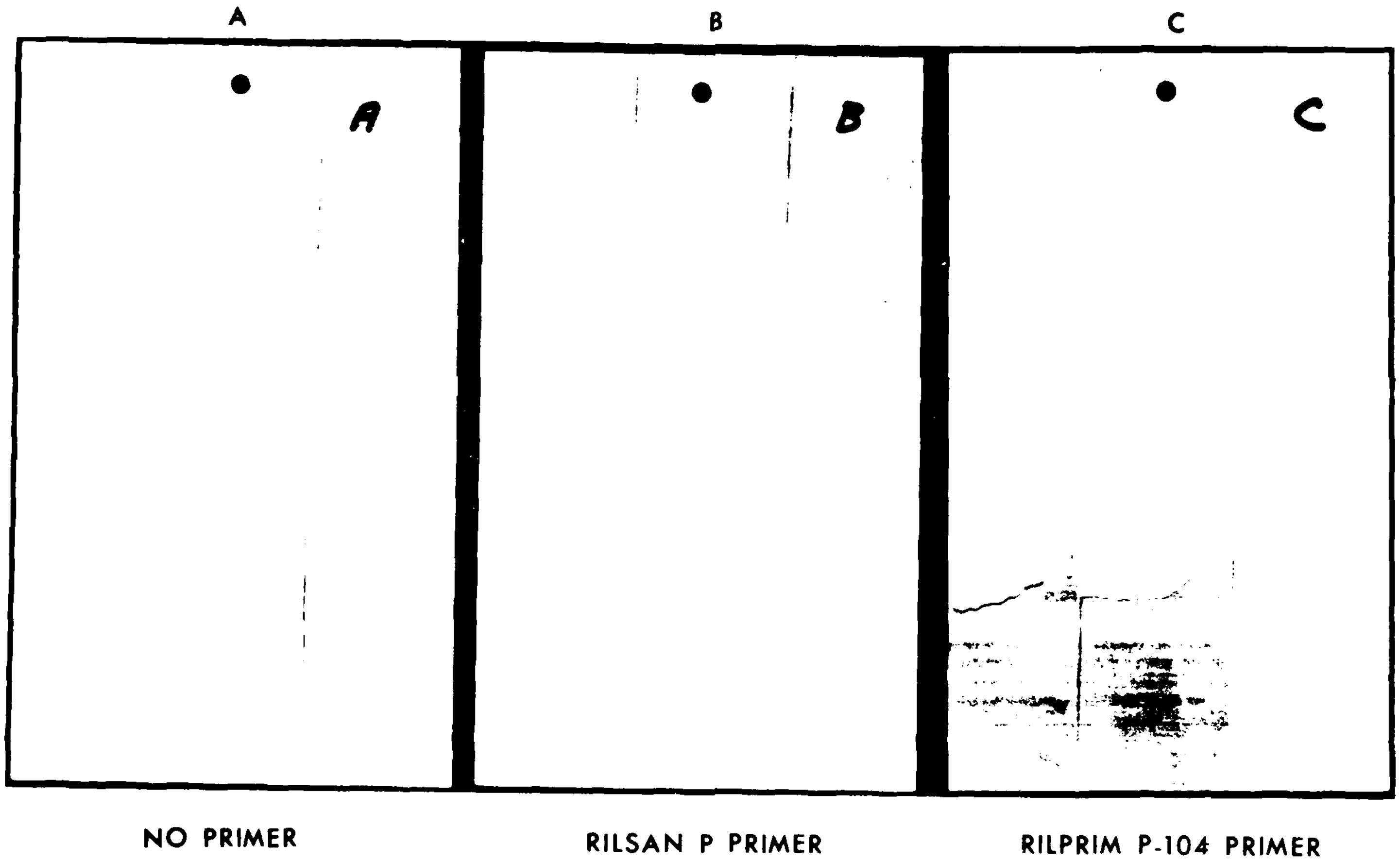


FIGURE 5A. WET AND DRY ADHESION TEST - NYLON TOPCOAT

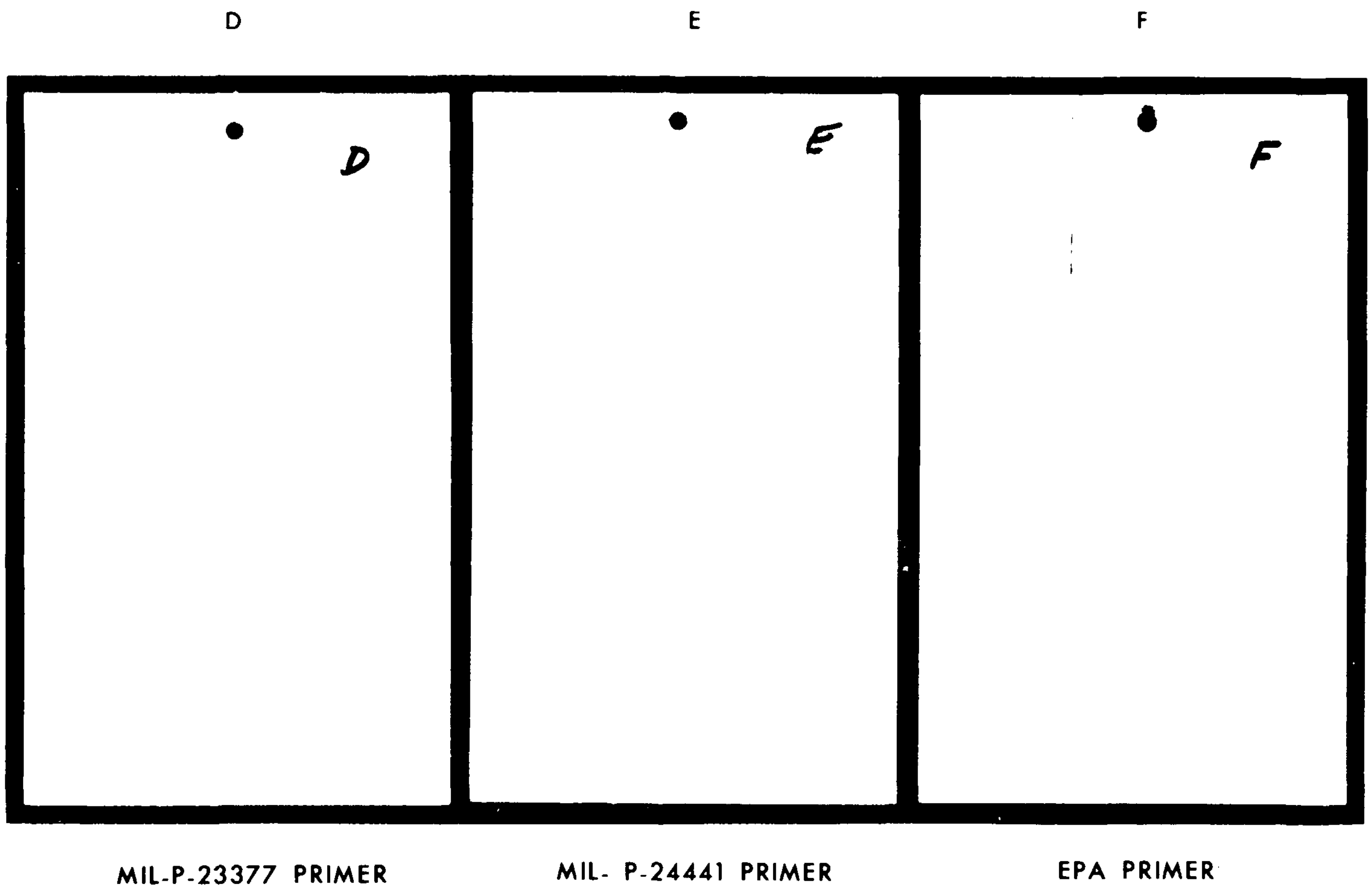


FIGURE 5B. WET AND DRY ADHESION TEST - NYLON TOPCOAT

ACID-ALKALI RESISTANCE TEST

Panels coated with the selected primers and topcoated with the powdered coatings were partially immersed at room temperature in battery acid electrolyte (29 degree baume' sulphuric acid) for a period of 14 days. Prior to immersion, the edges of the test panels were coated with paraffin wax to prevent chemical attack of the aluminum and subsequent premature coating failures. Following the 14 day immersion test, the panels were rinsed with tap water neutral to litmus paper, dried and examined for blistering, film degradation and other coating defects. The panels were then subjected to the scribed dry tape adhesion test.

Upon completion of the acid resistance test, the opposite ends of each test panel were subjected to the alkali soak test. The test procedure consisted of forming a raised circular barrier (1/4 inch wide and 1/2 inch high (0.63 cm x 0.127 cm) using a polysulphide sealant resistant to 2N sodium hydroxide. The enclosed circular paint area was approximately 1-1/2 inches (3.81 cm) in diameter. The 2 N NaOH solution was then poured into the recessed area of the coated panel and maintained at the desired concentration using distilled water to maintain the 2 N NaOH concentration. Upon completion of a seven day test period, the panels were rinsed thoroughly and the polysulphide barrier removed. The test area was then cleaned thoroughly with a one percent solution of a non-ionic detergent (Triton X-100), rinsed and dried. The test panels were immediately examined with a 10X lens for film defects and then subjected to the dry tape adhesion scribe test.

Note: The immersion test described for the acid resistance test could not be utilized for the alkali resistance test. The 2 N NaOH readily softened the protective paraffin wax, chemically attacking the panel edge with resultant substrate and coating failure.

Table III illustrates the condition of the test panels subjected to the acid and alkali immersion tests. All of the selected topcoats, regardless of the selected primer, passed the 14 day acid immersion test, as well as the panels that were not primed (bare) before topcoating.

An additional proprietary epoxy powder coating was included in the testing and is designated as Dridex 99X201, Midland Division, Dexter Chemical Corporation, Waukegan, Illinois. The coating, cured at 400°F (204°C) for 15 minutes, was selected to obtain data as compared to the epoxy LT (low temperature) and epoxy HT (high temperature-chemical resistant) powder coatings.

From the results in Table III it is evident that the applied powder coatings did not perform as well when subjected to the alkali resistance test. The epoxy coatings (HT) and Dridex 99X201 along with the nylon and polypropylene powdered coatings, passed the alkali test regardless of the applied primer finish. The epoxy (LT) coating however, failed the alkali test when applied over the Rilsan P and Rilprin P-104 primers, and passed when applied over the MIL-P-23377. The urethane powdered topcoat behaved in the same manner as the epoxy (LT) coating. It appears that the epoxy polyamide primer MIL-P-23377,

TABLE III. CHEMICAL RESISTANCE TEST DATA

Acid Test: Time - 14 Days @ Room Temperature
Alkali Test: Time - 7 Days @ Room Temperature

Substrate - 2024 Aluminum Bare-Chromate Treated

Topcoat	Acid Test Primer Coat			Alkali Test Primer Coat		
	RP	P-104	P-23377	RP	P-104	P-23377
Cellulose Acetate Butyrate	(1) P	P	P	P	P	F
Epoxy (LT)	P	P	P	F (2) (MPC)	F (3) (EPC)	P
Epoxy (HT)	P	P	P	P	P	P
(5) Epoxy (STD)	P	P	P	P	P	P
Nylon	P	P	P	P	P	P
Polyester	P	P	P	F (MPC)	P	P
Polypropylene	P	P	P	P	P	P
Urethane	P	P	P	F (4) (SPC)	F (MPC)	P

	Acid Test P-23377		Alkali Test P-23377
MIL-C-81733	P	No Test	P

NOTES:
(1) P (Pass) (2) Fail
(2) (MPC) - Moderate Pitting Corrosion
(3) (EPC) - Extensive Pitting Corrosion
(4) (SPC) - Severe Pitting Corrosion
(5) (STD) - Standard Epoxy Dridex 99X201 Dexter Chemical Corporation

because of its good chemical resistance, upgrades the applied topcoat finish, and prevents coating deterioration when the alkali solution permeates through the applied topcoat to the protective primer finish.

Figures 6 and 7 illustrate this phenomenon. For example, Figure 6 shows three test panels primed with the Rilsan P, Rilprim P-104 and MIL-P-23377 primers, and topcoated with the epoxy (LT) powder. Panel A and B of Figure 6 exhibit pitting pin-point corrosion, where as Panel C is corrosion free. The alkaline solution permeated the topcoat and primer finish, resulting in pitting of the substrate aluminum. Figure 7 shows the same phenomenon as Figure 6, except urethane was utilized as the powdered topcoat. Figure 8 presents panels primed in the same manner, but topcoated with the epoxy HT (chemical resistance) coating. As illustrated in the photo and in Table III, all of the coatings passed the alkali test.

A coating test, to be meaningful is often compared to coating data derived from testing a comparative coating system. Therefore, test panels painted with the standard MIL-P-23377 epoxy primer, and topcoated with the standard MIL-C-81773 linear urethane topcoat (a solvent based system), were also subjected to the alkali test. It is interesting to note that the standard Navy paint system passed the acid and alkali test as illustrated in Table III and Figure 9.

FLEXIBILITY TESTS

The thermosetting and thermoplastic topcoats, with and without the selected primer coats, were subjected to the cylindrical mandrel and impact flexibility tests. The flexibility of coatings applied to fairly rigid substrates is measured by bending a coated panel over a specified size mandrel. A 1/4 inch (0.63 cm) mandrel was utilized to measure the flexible properties of the powdered coatings.

The impact-resistance test was utilized to measure the toughness and adhesion properties of the applied coatings. The impact test, therefore, determines the ability of the coating to resist shattering, cracking or chipping when the paint film and substrate are distended beyond their original form by impact. The G.E. Impact Tester consists of a metal cylinder which is dropped through a guide track from a height of approximately four feet. The cylinder strikes the uncoated side of the test panel. Each end of the dropping cylinder is studded with a group of spherical knobs arranged in a circle. When the cylinder strikes the panel, the knobs distend the coating according to the curvature of the respective knob. The knobs are calibrated in terms of percent based on the elongation they produce on the metal panel. The percent draw for the various studs are 1/2, 1, 2, 5, 10, 20, 40 and 60 respectively. After impact, the panel is examined under 10X magnification. The stud (elongation) with the greatest draw where no film defects are found is reported as the percent elongation.

The coatings were applied to 3 x 6 x 0.020 inch (7.62 x 15.24 x 0.05 cm) 2024 (0-temper) aluminum test panels anodized to meet MIL-C-8625, Type II specification requirements. The mandrel bend and impact tests were

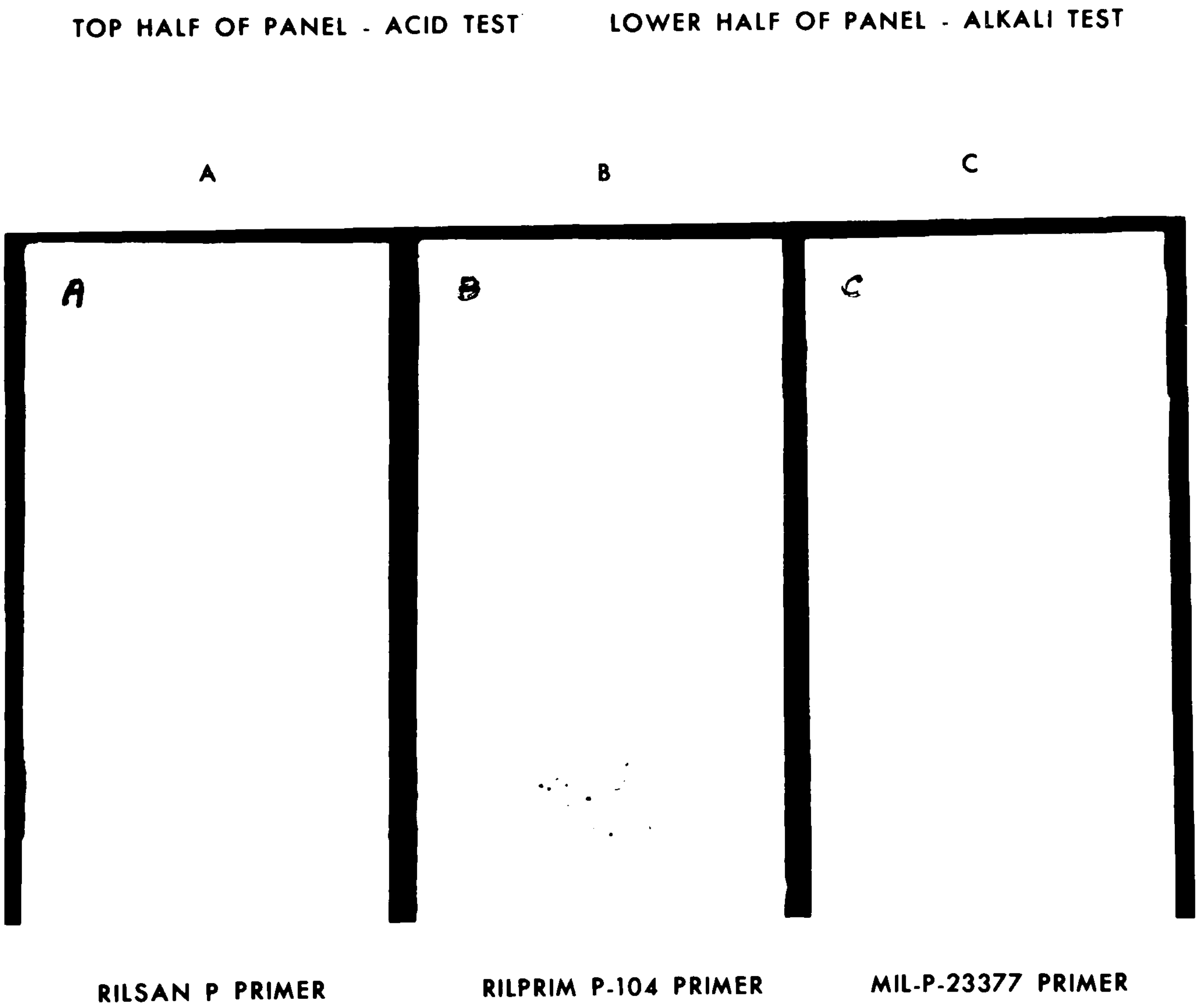


FIGURE 6. CHEMICAL RESISTANC TEST - EPOXY (LT) TOPCOAT

TOP HALF OF PANEL - ACID TEST LOWER HALF OF PANEL - ALKALI TEST

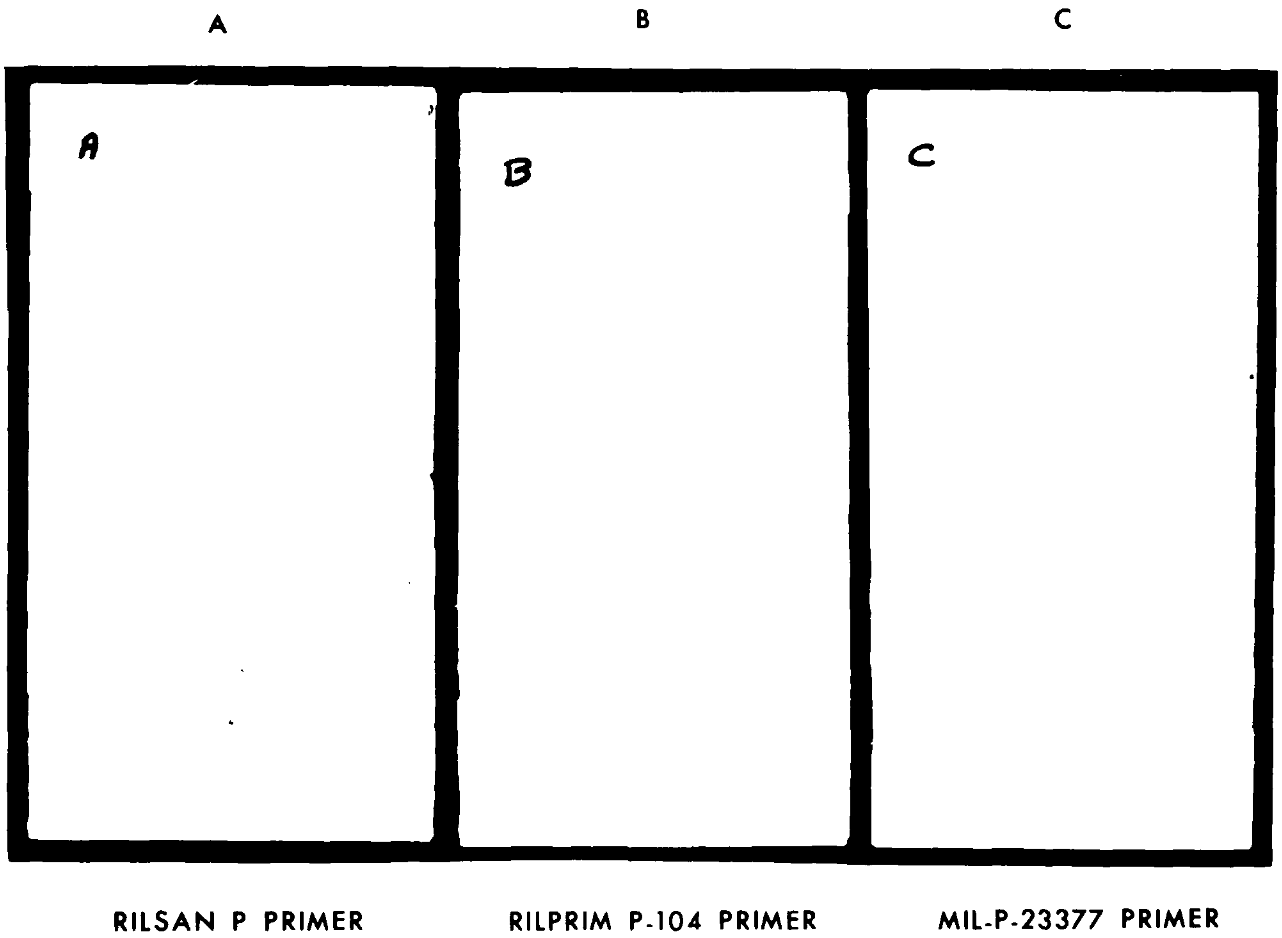


FIGURE 7. CHEMICAL RESISTANCE TEST - URETHANE TOPCOAT

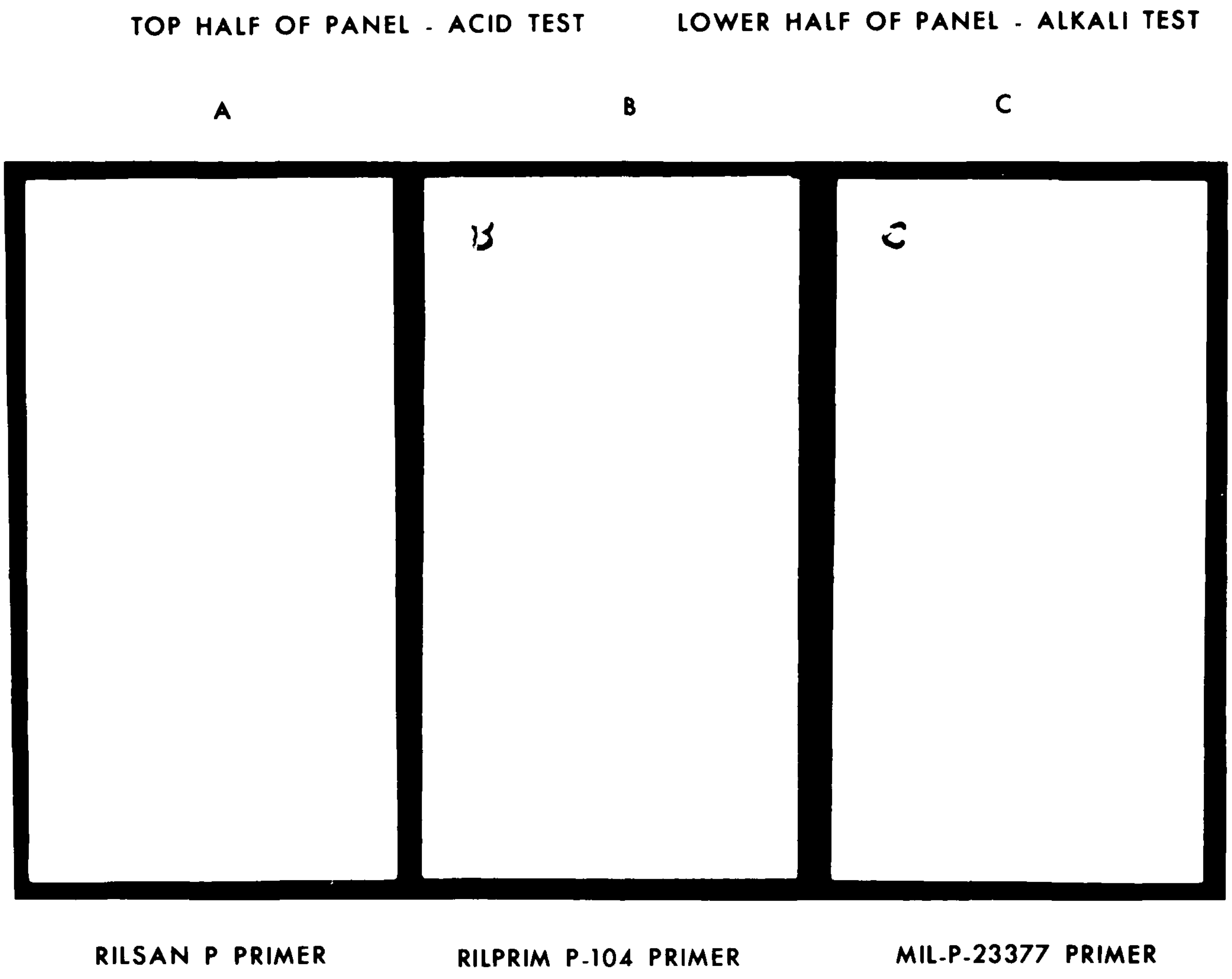


FIGURE 8. CHEMICAL RESISTANCE TEST - EPOXY (HT) TOPCOAT

TOP HALF PANEL — ACID TEST
LOWER HALF PANEL — ALKALI TEST

PRIMER - MIL-P- 23377 (EPOXY POLYAMIDE)
TOPCOAT - MIL-C-81773 (LINEAR URETHANE)
SOLVENT BASED COATING SYSTEM

FIGURE 9. CHEMICAL RESISTANCE TEST

conducted at cold temperatures only (-70° ± 5°F) (-56° ± 3°C). Room temperature studies were not included, as studies in the past have shown that coatings, to be acceptable for aircraft applications, must exhibit good **adhesion, flexibility and impact properties at the low temperatures to which aircraft surfaces are subjected.** Table IV illustrates the properties of the powdered coatings applied to bare aluminum substrates as well as primed surfaces. To obtain comparative test data, the table also shows the properties of the standard solvent-based Navy coating which consists of the MIL-P-23377 epoxy polyamide primer topcoated with the linear MIL-C-81773B urethane finish. A glance at the mandrel bend test data will show that none of the powdered topcoats, except nylon, passed the mandrel bend test. Also the solvent based urethane coating, as illustrated in Figure 14, passed the bend test. In relation to the G.E. Impact Test, the nylon coating was also outstanding in that it passed the maximum percent elongation (60) when applied alone (no primer) and when applied over the MIL-P-23377C epoxy primer. The other powdered coatings were not outstanding, and as illustrated, gave elongation readings slightly inferior to the solvent based MIL-C-81773B linear urethane coating.

Figure 10 is included to illustrate the excellent mandrel and impact properties of the nylon coated test panels. Figures 11, 12 and 13 illustrate the mandrel bend and impact test results in the epoxy (LT), polyester and urethane powdered coatings respectively. Coated test panels without a primer undercoat, show spalling, (coating failure to substrate) at the high distensibility impacts of 20, 40, and 60 percent. Also, Figure 12 shows that spalling occurred on the mandrel bend test of Panel A as the coating shows poor adhesion to the substrate. The coatings (epoxy LT and urethane) illustrated in Figures 11 and 13, did not spall when subjected to the mandrel bend test, but exhibit linear cracking.

Figure 14 is included to compare the standard MIL-P-23377 (epoxy primer) and MIL-C-81773 (linear urethane) topcoated paint system to the solventless powder coated systems. Panel A exhibits the G.E. impact test where the coating passed the one percent elongation test. Panel B illustrates the 1/4 inch and 1/8 inch mandrel bend test, the coating passing the 1/4 inch test, but failing the 1/8 inch test due to fine lateral cracks evident, using a 10X lens.

HUMIDITY EXPOSURE TEST

The powdered coatings, with and without selected primer undercoats, were subjected to the humidity cabinet (Army-Navy Aero Specification AN-H-31) at 120 ± 2°F (49 ± 2°C) and one hundred percent relative humidity for 14 days. Upon completion of the test period, the panels were wiped dry and allowed to condition to room temperatures for one hour. The panels were then scored to the substrate using a sharp stainless steel scribe. One inch wide masking tape (3M 120) was then firmly applied to the cross-hatched coating surface and removed in one abrupt motion. The panels were then examined for intercoat and/or primer to substrate adhesion.

To obtain comparative test data related to electrostatically applied powder coatings versus conventionally sprayed solvent based coatings, two test panels coated with one coat of MIL-P-23377 epoxy primer, and two coats

TABLE IV. CYLINDRICAL MANDREL AND G.E. IMPACT TEST DATA

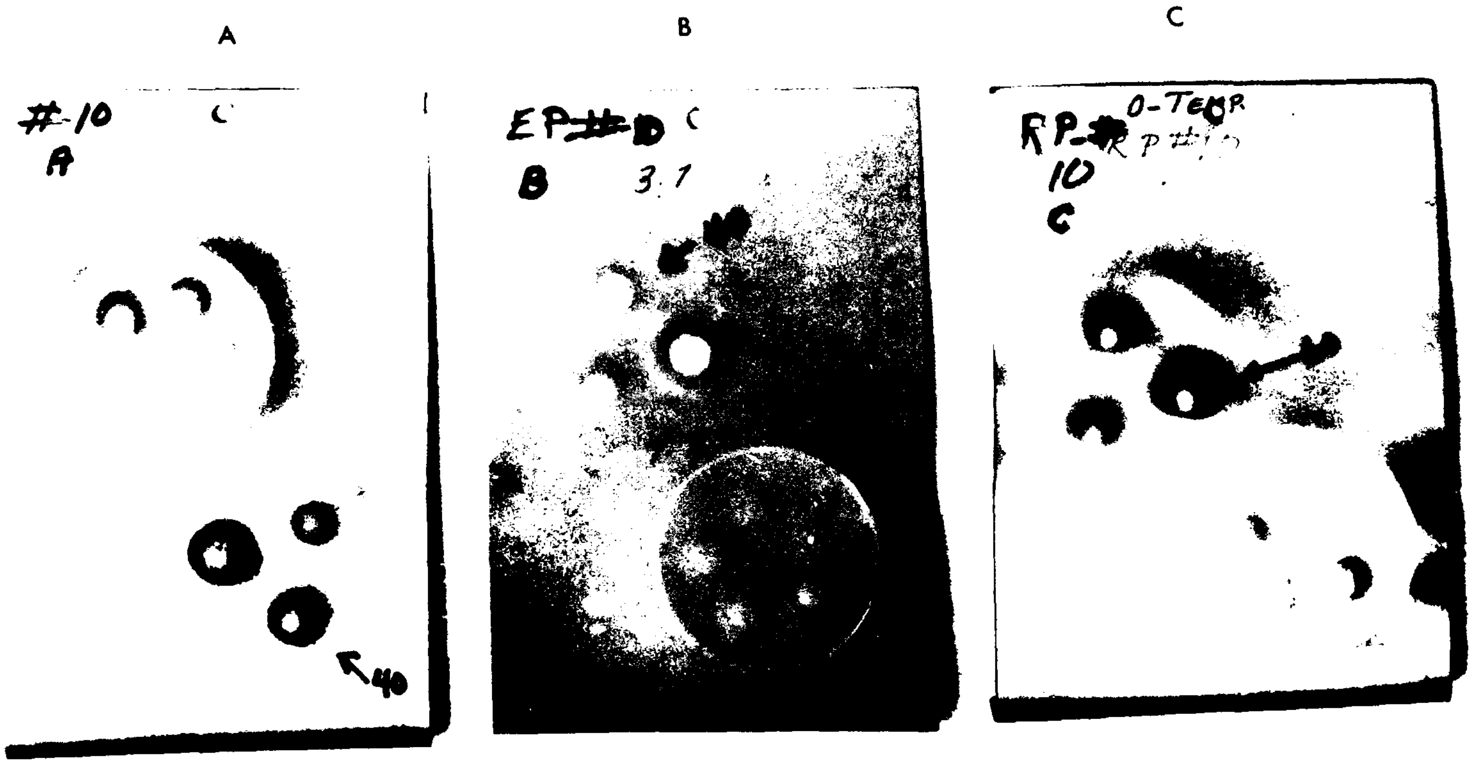
COLD: (-70° ± 5°F) (-56° ± 3°C)

Applied Powder Topcoat	Mandrel Bend (1/4 inch)			G.E.Impact - Percent		
	None	Rilsan P	MIL-P-23377	None	Rilsan P	MIL-P-23377
Cellulose Acetate Butyrate	Fails (LC)	Fails (LC)	Fails (SP)	2	1/2	1/2
Epoxy (LT)	Fails (FLC)	Fails (FLC)	Fails (FLC)	1/2	1	1
Epoxy (HT)	Fails (FLC)	Fails (FC)	Fails (LC)	1	1	1
Nylon	Passes	Passes	Passes	40	40	60
Polyester	Fails (FLC)	Fails (SP)	Fails (FLC)	Fails 1/2	2	1/2
Polypropylene	Fails (SP)	Fails (LC)	Fails (SP)	Fails 1/2	1/2	Fails 1/2
Urethane	Fails (FLC)	Fails (FC)	Fails (FC)	1/2	1/2	1/2
Vinyl	Fails (SP)	Fails (SP)	Fails (SP)	1/2	Fails 1/2	Fails 1/2
* MIL-C-81773	No Test	No Test	Fails	No Test	No Test	1

Codes:
(FLC) - Fine Linear Cracks, Using 10X Lens
(LC) - Linear Cracks - No Lens Require
(SP) - Spalling (Coating Breaks Away from Substrate)

* Standard Naval Aircraft Coating System (Solvent Based)
Cylindrical Mandrel Test (180° Bend): Para 4.6.7 of MIL-C-81773
G.E. Impact Test: Fed. Test Std. 141, Method 6226

NYLON TOPCOAT



NO PRIMER

RILSAN P PRIMER

MIL-P- 23377 PRIMER

FIGURE 10. CYLINDRICAL MANDREL AND G.E. IMPACT TEST

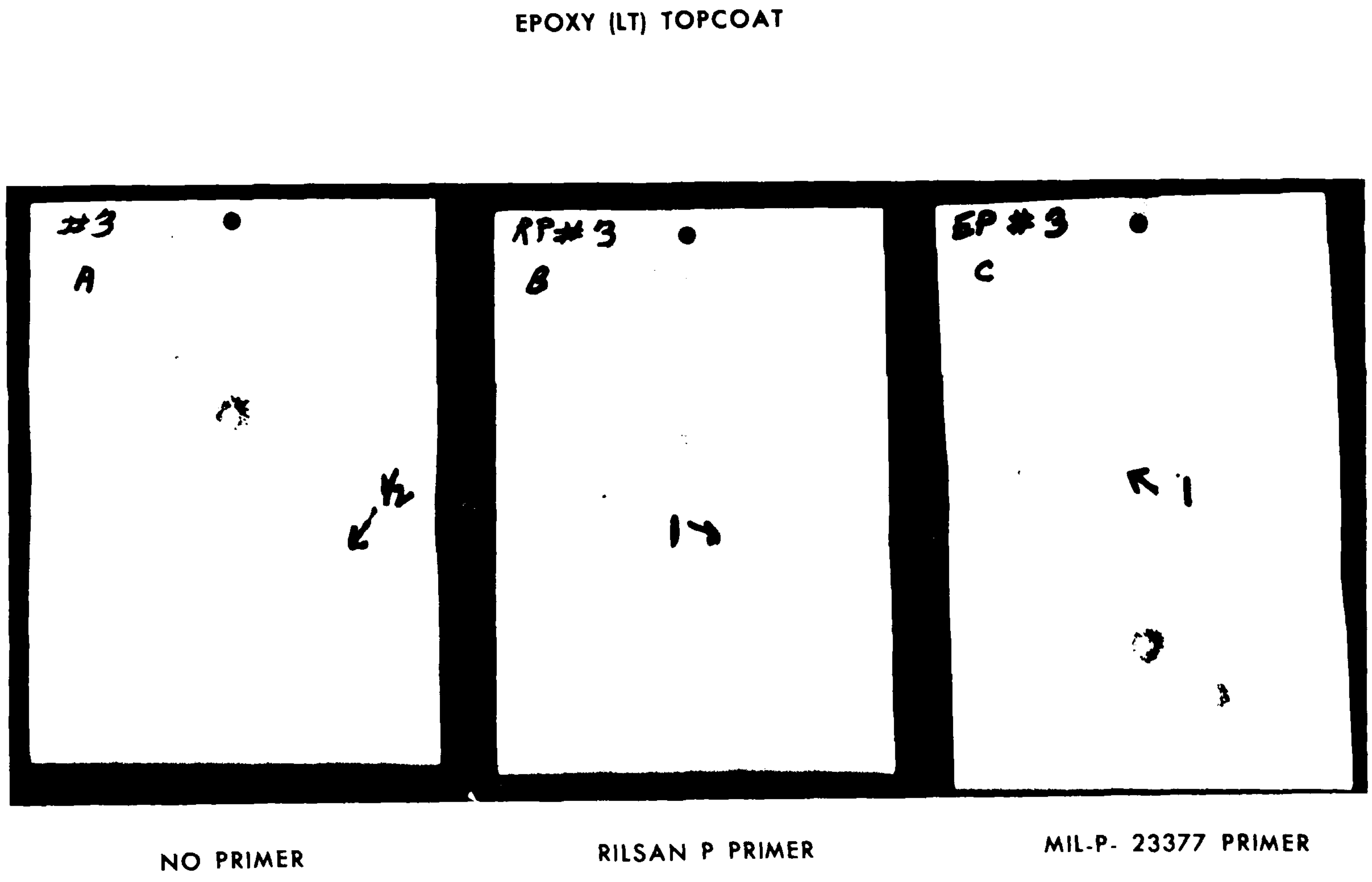


FIGURE 11. CYLINDRICAL MANDREL AND G.E. IMPACT TEST

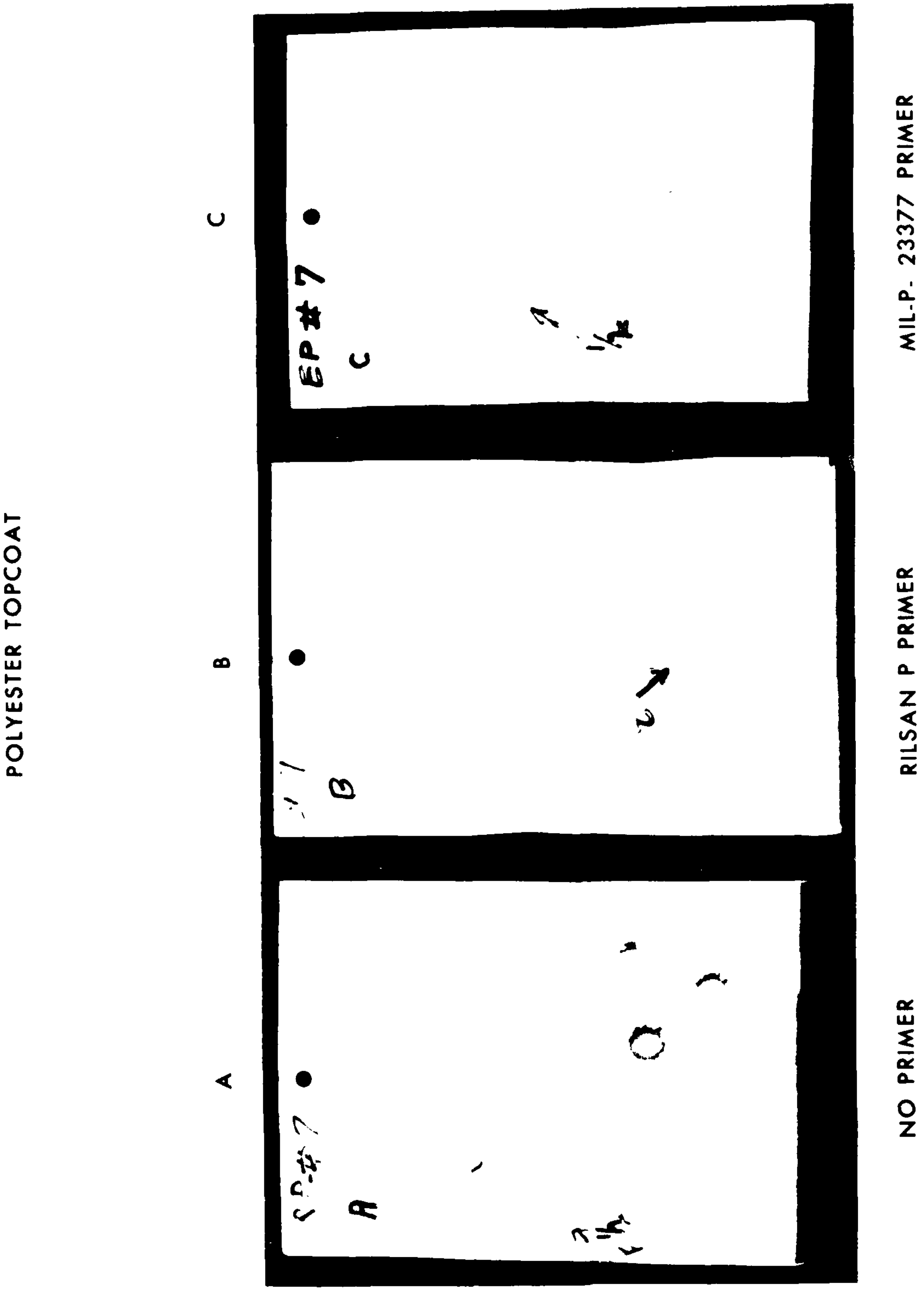


FIGURE 12. CYLINDRICAL MANDREL AND G.F. IMPACT TEST

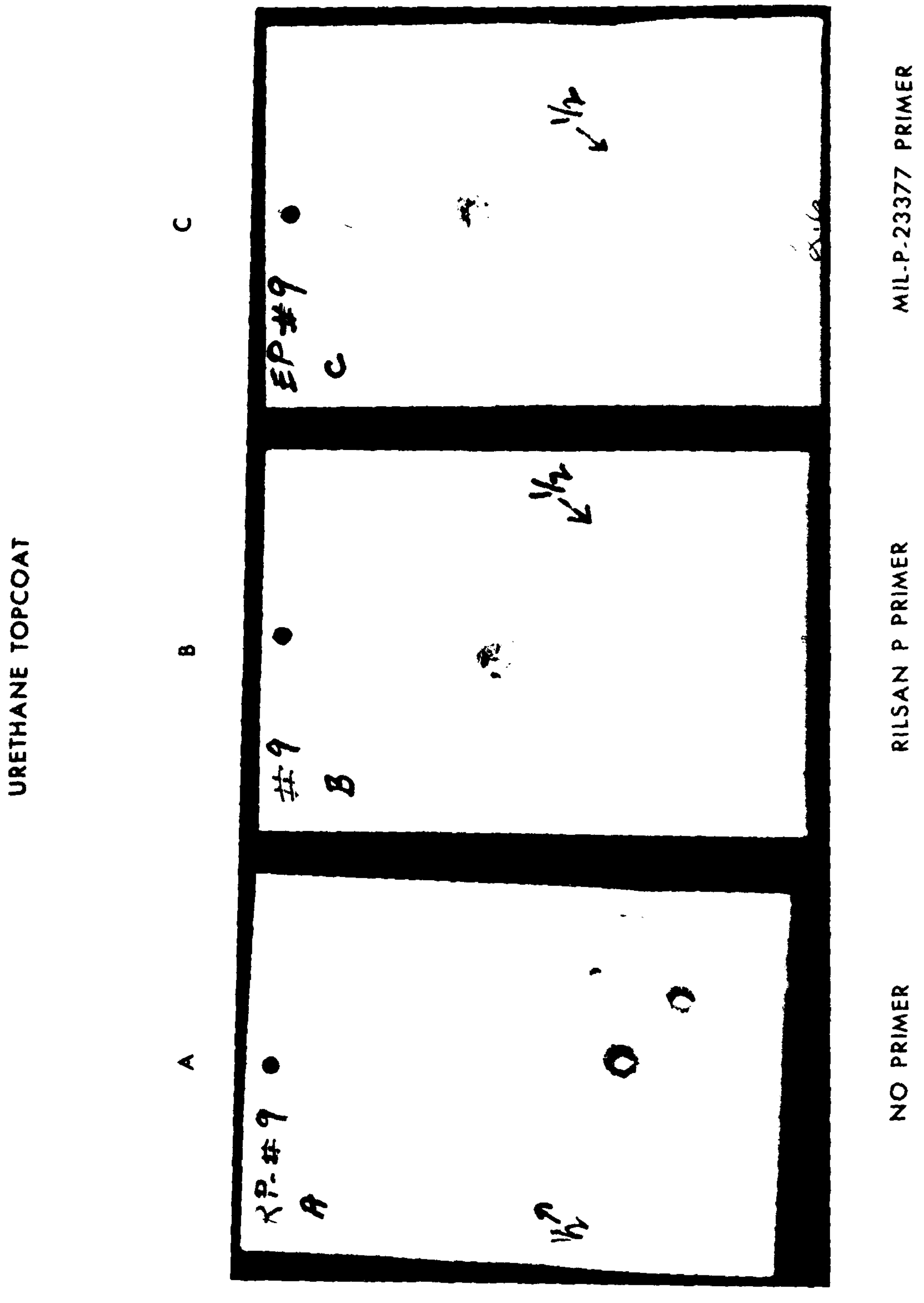
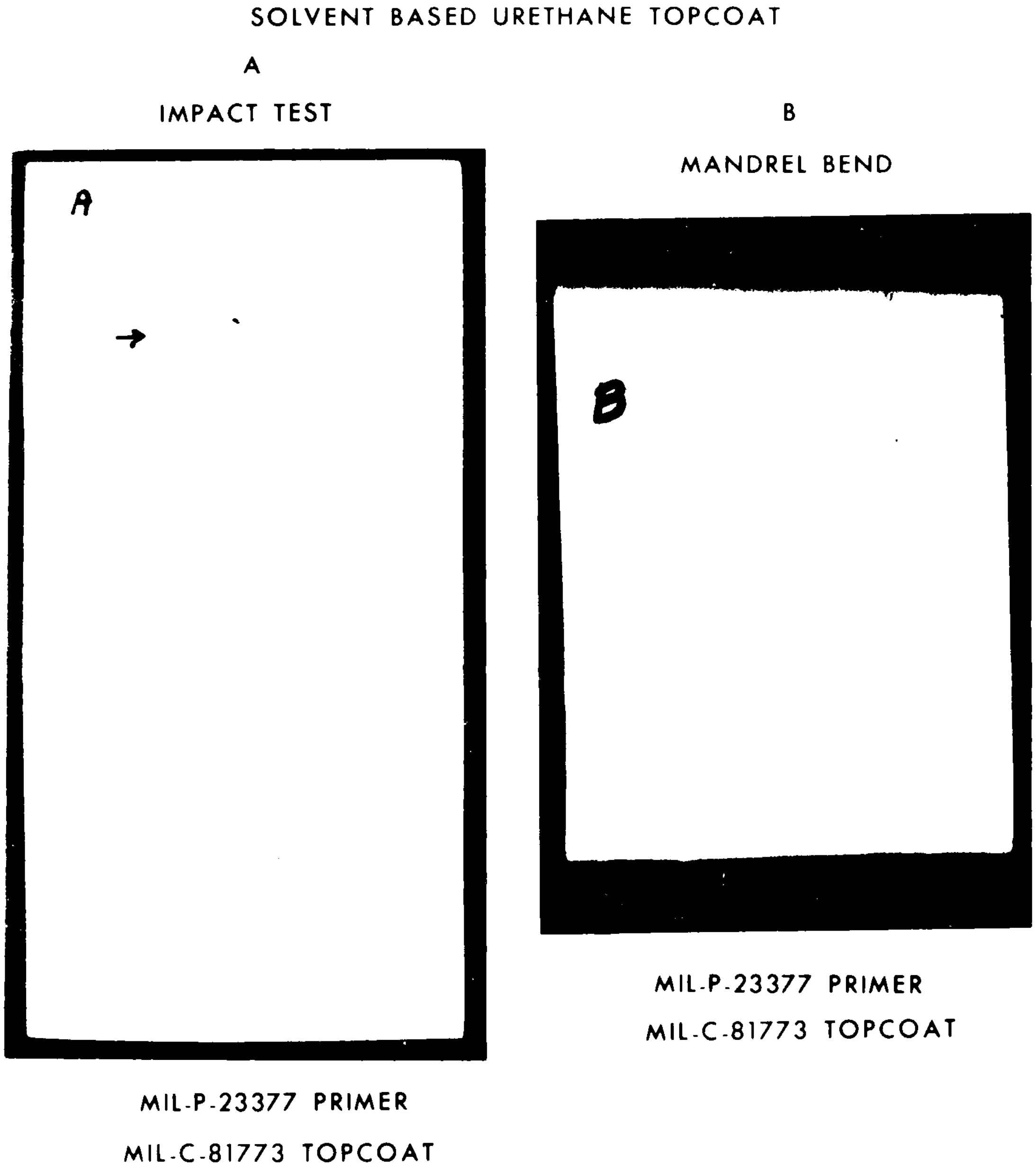


FIGURE 13. CYLINDRICAL MANDREL AND G.E. IMPACT TEST



SOLVENT BASED URETHANE TOPCOAT

A

IMPACT TEST

MIL-P-23377 PRIMER

MIL-C-81773 TOPCOAT

B

MANDREL BEND

MIL-P-23377 PRIMER

MIL-C-81773 TOPCOAT

FIGURE 14. CYLINDRICAL MANDREL AND G.E. IMPACT TEST

of MIL-C-81773 urethane topcoat were also subjected to the humidity test as control specimens. All of the coatings were applied to 3 x 6 x 0.020 inch (7.62 x 15.24 x 0.05 cm) 2024 bare aluminum test panels pretreated with a chemical conversion coating meeting specification MIL-C-5541, Class 1A requirements.

As illustrated in Table V the polyester, polypropylene, nylon and urethane coatings, without the selected primers as the undercoat, were not affected by the 14 day humidity exposure test. The fast cure epoxy (LT) and chemical resistant epoxy (HT) coatings exhibited coating failures only when applied over the R-P (Rilsan one component primer), both failures occurring to the substrate. The CAB (cellulose acetate butyrate) coating failed to be compatible with the epoxy primer, as the exposed test panels resulted in intercoat adhesion failures. The only vinyl coated test panels which passed the humidity test were the epoxy primed-vinyl topcoated panels. The remaining vinyl coated panels, with and, without the designated Rilsan primers, blistered and failed to the substrate.

The control panels painted with the standard coating system (MIL-P-23377 primer and MIL-C-81773 urethane topcoat), were not affected by the 14 day exposure test. This was to be expected as the MIL-P-23377 primer, with or without the urethane topcoat, has excellent moisture resistant properties and adhesion properties.

NaCl-SO_2 EXPOSURE TEST

Corrosion studies were conducted to obtain coating data on selected one and two component corrosion inhibitive primers applied to magnesium test panels topcoated with fast-low-temperature cure and chemical resistant type epoxy powdered coatings.

Epoxy powder coatings and magnesium substrate test panels were selected for the NaCl-SO_2 studies for two reasons:

1. The need for a corrosion inhibitive primer topcoated with a durable abrasion resistant topcoat is urgently needed to protect magnesium alloy component parts; and

2. Epoxy thermosetting powders are usually preferred for industrial applications because they exhibit good corrosion and chemical resistance.

The exposure test panels measuring 3 x 6 x 0.020 in. (7.62 x 15.24 x 0.05 cm) were AZ 31B-H24 magnesium alloy meeting the requirements of Federal Specification QQ-M-44. The panels were divided into eight groups, each group containing five panels. The panels were precleaned, coated, cured and prepared for the NaCl-SO_2 salt chamber as follows:

1. Solvent wipe panels using methyl ethyl ketone solvent, Federal Specification TT-M-261b.

2. Apply "X" marks to the center of each panel using 1/8 inch

TABLE V. HUMIDITY CHAMBER TEST DATA

Exposure Time - 14 Days

Temperature - $120 \pm 3^{\circ}$F ($49 \pm 2^{\circ}$C)

Applied Primer	Applied Topcoat	Condition of Coating
A	Cellulose Acetate Butyrate	NCF
B	Cellulose Acetate Butyrate	NCF
C	Cellulose Acetate Butyrate	NCF
D	Cellulose Acetate Butyrate	*CF (1C)
A	LT Epoxy	NCF
B	LT Epoxy	*CF (SF)
C	LT Epoxy	NCF
D	LT Epoxy	NCF
A	HT Epoxy	NCF
B	HT Epoxy	*CF (SF)
C	HT Epoxy	NCF
D	HT Epoxy	NCF
A	Nylon	NCF
B	Nylon	NCF
C	Nylon	NCF
D	Nylon	NCF
A	Polyester	NCF
B	Polyester	NCF
C	Polyester	NCF
D	Polyester	NCF
A	Polypropylene	NCF
B	Polypropylene	NCF
C	Polypropylene	NCF
D	Polypropylene	NCF
A	Urethane	NCF
B	Urethane	NCF
C	Urethane	NCF
D	Urethane	NCF
A	Vinyl	*CF (SF)
B	Vinyl	*CF (SF)
C	Vinyl	*CF (SF)
D	Vinyl	NCF
D	Urethane	NCF

Coating Codes:

A - No Primer Coat
B - Rilsan P Primer
C - Rilprim 104 Primer
D - Mil-P-23377 Primer
- MIL-C-81773 (Solvent Based) Control Coating

Test Codes:

NCF - No Coating Failures
*CF - Coating Failure
(1C) - Intercoat Failure
(SF) - Failure to Substrate

(0.32 cm) pressure sensitive plastic tape. The "X" letter was 1.5 in. (3.8 cm) high and 0.75 in. (1.91 cm) wide.

3. Apply the selected primers to the prepared test panels to a film thickness of 0.6 to 0.8 mils (15.24 to 20.3 μm thick). Allow the primer coatings to air dry 24 hours.

4. Electrostatically apply the selected epoxy powder coatings to the primed panels.

5. Cure the topcoated panels in a force draft oven as follows:

Fast Cure Epoxy Topcoat - $300^{\circ} \pm 3^{\circ}F$ ($148 \pm 2^{\circ}C$) for 12 minutes.

Chemical Resistant Epoxy Topcoat - $350^{\circ} \pm 3^{\circ}F$ ($176 \pm 2^{\circ}C$) for 15 minutes.

NOTE: Panels were removed from the oven after a two minute cure time. The plastic "X" tape mark was removed, and the panels returned to the oven for the remaining bake (cure) period.

6. After baking, the panels were cooled to room temperature, then solvent wiped in the "X" area using a clean cloth dampened with aliphatic naptha, TT-N-97 to remove any residual adhesive that might have deposited from the pressure sensitive tape.

7. The reverse side of each panel was primed with two coats of MIL-P-23377C primer to prevent corrosion during the NaCl-SO_2 test.

8. The edges of all test panels were dipped in hot parraffin wax to prevent peripheral corrosion from initiating at the sheared edges.

Five test panels from each group were coated with the selected primer. Two of the five panels were topcoated with the fast cure epoxy topcoat (LT) and two panels coated with the chemical resistant epoxy topcost (HT). The remaining test panel, coated with the primer only, was utilized as the control. Prior to painting and subjecting the test panels to the NaCl-SO_2 cabinet, masked off " X" marks were utilized in lieu of the conventional mechanically scribed "X". The masked off "X" technique was selected for two reasons:

1. Mechanical scribing of painted magnesium panels severely damages the substrate metal. The damage imposed to the soft and highly anodic substrate is not indicative of the surface defects generally found on painted engine components such as fixed and rotary wing transmission gear boxes, housings and associated component parts.

2. Scribe marks result in a rough, deep, and irregular metal defect which entraps the electrolyte into the grain boundaries, thereby creating rapid exfoliation (intergranular) type of corrosion that results in failures

that are difficult to repeat and relate to the effectiveness of a protective coating system.

By utilizing the masked off "X" tape technique, the substrate on all test panels **remains undamaged and intact.** This allows corrosion phenomena to chemically initiate and progress in a controlled manner, without inducing a point of initiation to the metal substrate that is difficult to repeat in depth and size using the mechanical scribe method.

Table VI lists the primer and powder topcoats selected for the NaCl-SO_2 exposure studies. The specification primers selected are currently being utilized to protect naval aircraft and ships. The selection of the proprietary primers was based on test data derived from past studies.

The photographs of the test panels after the 1000 hour NaCl-SO_2 exposure period are illustrated as Figures 15 through 23, each figure illustrating a duplicate set of test panels primed and topcoated as specified in Table VI. The primer that exhibited the poorest protection was specification MIL-C-8514 primer. The primer coating blistered after an exposure period of 280 hours and was removed from the test after a period of 360 hours as the panel showed extensive pitting corrosion. Primers identified as Rilsan P and TT-P-1757 showed minor coating failures at the 280 hour exposure period and extensive failure (pitting corrosion) after the 360 hour exposure period. The panels were removed from the exposure chamber after completing 500 hours of exposure. Rilprim P-104 primer showed very slight pitting corrosion after an exposure period of 328 hours and heavy pitting corrosion at the 360 hour exposure period. The test panel was removed from the test after being exposed for a 600 hour period.

Rilsan P and TT-P-1757 primers are one component types, whereas MIL-C-8514 and Rilprim P-104 are two component primers utilizing phosphoric acid as the second component. The poor performance of the TT-P-1757 as a corrosion protective primer was expected, as alkyd based coatings usually perform well in a salt (NaCl) spray test, but are attacked by the SO_2 (sulphur dioxide) present in the NaCl-SO_2 test. The NaCl-SO_2 exposure test **is a more severe** test than the conventional sea salt (NaCl) test.

The two component epoxy polyamide primers, MIL-P-23377 and MIL-P-24441, and the proprietary EPA (epoxy polyamine) primer all showed good to excellent corrosion protective properties when exposed to the NaCl-SO_2 exposure test. All three primers were extended to the 1000 hour exposure period. The first signs of minor pin-point pitting corrosion became evident after 800 hours exposure. The good performance illustrated by the two component chromate inhibited epoxy primers was expected, as the primers chemically cure to a tough, durable, and chemical resistant coating.

The proprietary two component amine cured epoxy primer (EPA) manufactured by DeSoto Inc., was included in the testing program to obtain test data related to an amine cured chromate inhibited primer as compared to the specification MIL-P-23377 amide cured chromate inhibited primer.

TABLE VI. NaCl-SO_2 EXPOSURE TEST

Substrate · Magnesium AZ31B-H24 Fed. Spec. QQ-M-44

Fig.		Primer	Topcoat	Av. Film Thickness Mils	Av. Film Thickness µm	Exposure Time Hours	Condition of Coating
15	A	MIL-C-8514	-	0.4	10.2	360	Severe pitting corrosion
	B	TT-P-1757	-	0.8	20.3	500	Severe pitting corrosion
	C	Rilsan P	-	0.4	10.2	500	Extensive pitting corrosion
	D	Rilprim P-104	-	0.4	10.2	600	Extensive pitting corrosion
16	E	MIL-P-23377	-	0.8	20.3	1000	○ No coating failures (minor pitting corrosion)
	F	MIL-P-24441	-	0.9	22.9	1000	○ No coating failures (minor pitting corrosion)
	G	EPA (Polyamine)	-	0.8	20.3	1000	○ No coating failures (minor pitting corrosion)
17	A	MIL-C-8514	LT	2.4	60.9	1000	* No coating failures
	B	MIL-C-8514	LT	2.4	60.9	1000	* No coating failures
	C	MIL-C-8514	HT	2.9	73.7	1000	* No coating failures
	D	MIL-C-8514	HT	2.9	73.7	1000	* No coating failures
18	A	Rilprim P-104	LT	2.0	50.8	1000	* No coating failures
	B	Rilprim P-104	LT	2.0	50.8	1000	* No coating failures
	C	Rilprim P-104	HT	3.5	88.9	1000	* No coating failures
	D	Rilprim P-104	HT	3.5	88.9	1000	* No coating failures
19	A	Rilsan P	LT	2.0	50.8	1000	Coating failure (poor intercoat adhesion)
	B	Rilsan P	LT	2.0	50.8	1000	Coating failure (poor intercoat adhesion)
	C	Rilsan P	HT	3.0	76.2	1000	* No coating failures
	D	Rilsan P	HT	3.0	76.2	1000	* No coating failures
20	A	MIL-P-23377	LT	3.5	88.9	1000	Slight amount of intercoat adhesion failure
	B	MIL-P-23377	LT	3.5	88.9	1000	Slight amount of intercoat adhesion failure
	C	MIL-P-23377	HT	4.0	101.6	1000	* No coating failures
	D	MIL-P-23377	HT	4.0	101.6	1000	* No coating failures
21	A	MIL-P-24441	LT	3.5	88.9	1000	Intercoat adhesion failure at "X"
	B	MIL-P-24441	LT	3.5	88.9	1000	Intercoat adhesion failure at "X"
	C	MIL-P-24441	HT	4.0	101.6	1000	* No coating failures
	D	MIL-P-24441	HT	4.0	101.6	1000	* No coating failures
22	A	TT-P-1757	LT	3.0	76.2	1000	* No coating failures
	B	TT-P-1757	LT	3.0	76.2	1000	* No coating failures
	C	TT-P-1757	HT	4.0	101.6	1000	* No coating failures
	D	TT-P-1757	HT	4.0	101.6	1000	* No coating failures
23	A	Polyamine (EPA)	LT	2.8	71.2	1000	Slight coating failure at "X"
	B	Polyamine (EPA)	LT	2.8	71.2	1000	* No coating failures
	C	Polyamine (EPA)	HT	4.0	101.6	1000	* No coating failures
	D	Polyamine (EPA)	HT	4.0	101.6	1000	* No coating failures
24	A	-	LT	2.0	50.8	1000	Coating failure at "X"
	B	-	HT	3.0	76.2	1000	No coating failure
	C	MIL-P-23377	MIL-C-81773	2.8			
	D	MIL-P-23377	MIL-C-81773	2.8			

NOTES: LT = Epoxy Powder Coating (Low Temperature Fusion)
HT = Epoxy Powder Coating (High Temperature Fusion)
* = Coating Exhibits Good Adhesion and Corrosion Protective Characteristics
○ = Primer Exhibits Good Corrosion Protective Properties
Figure 24 (C and D) = Standard Solvent Based Linear Urethane System

PRIMER ONLY

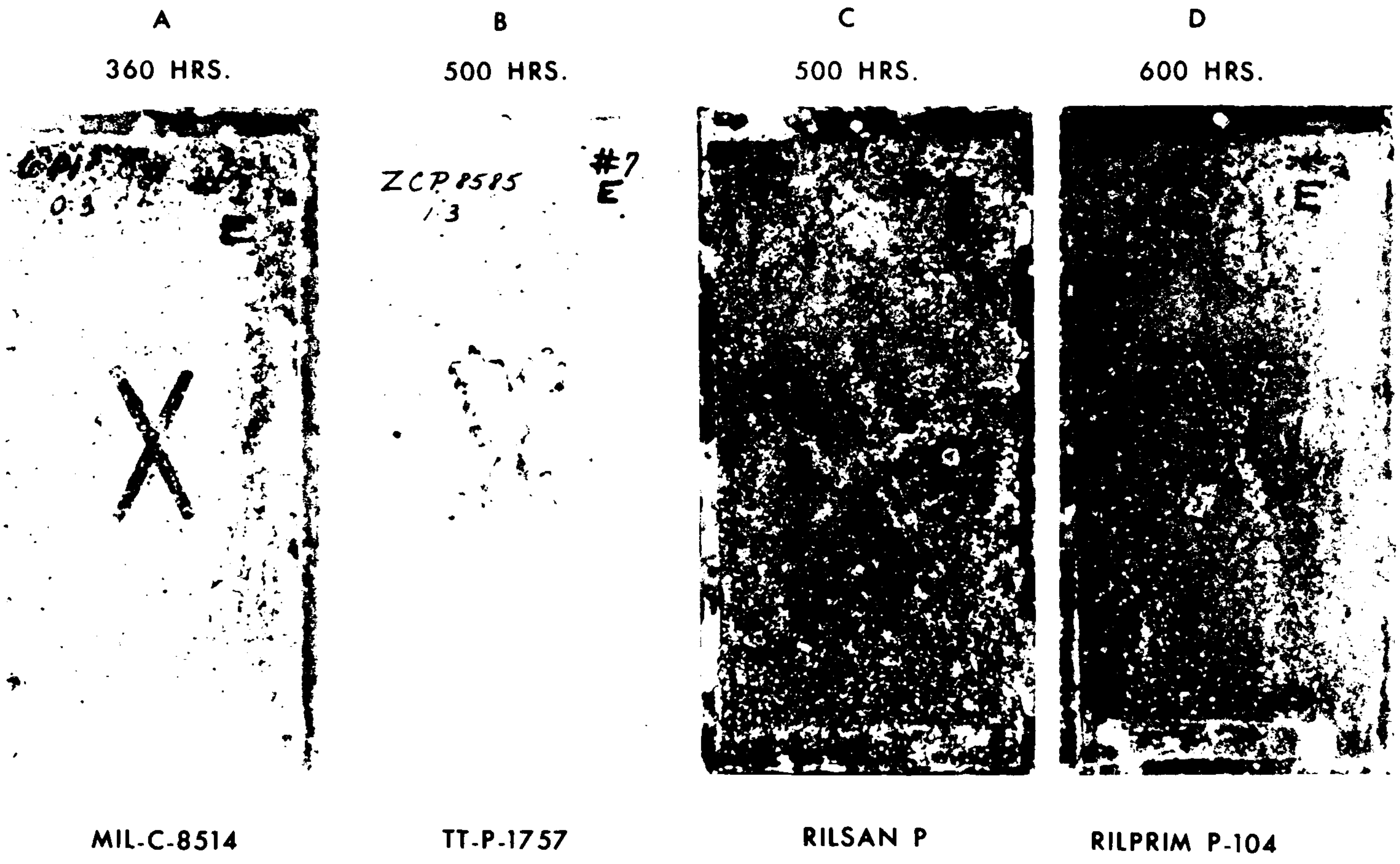


FIGURE 15. NaCL-SO_2 EXPOSURE TEST

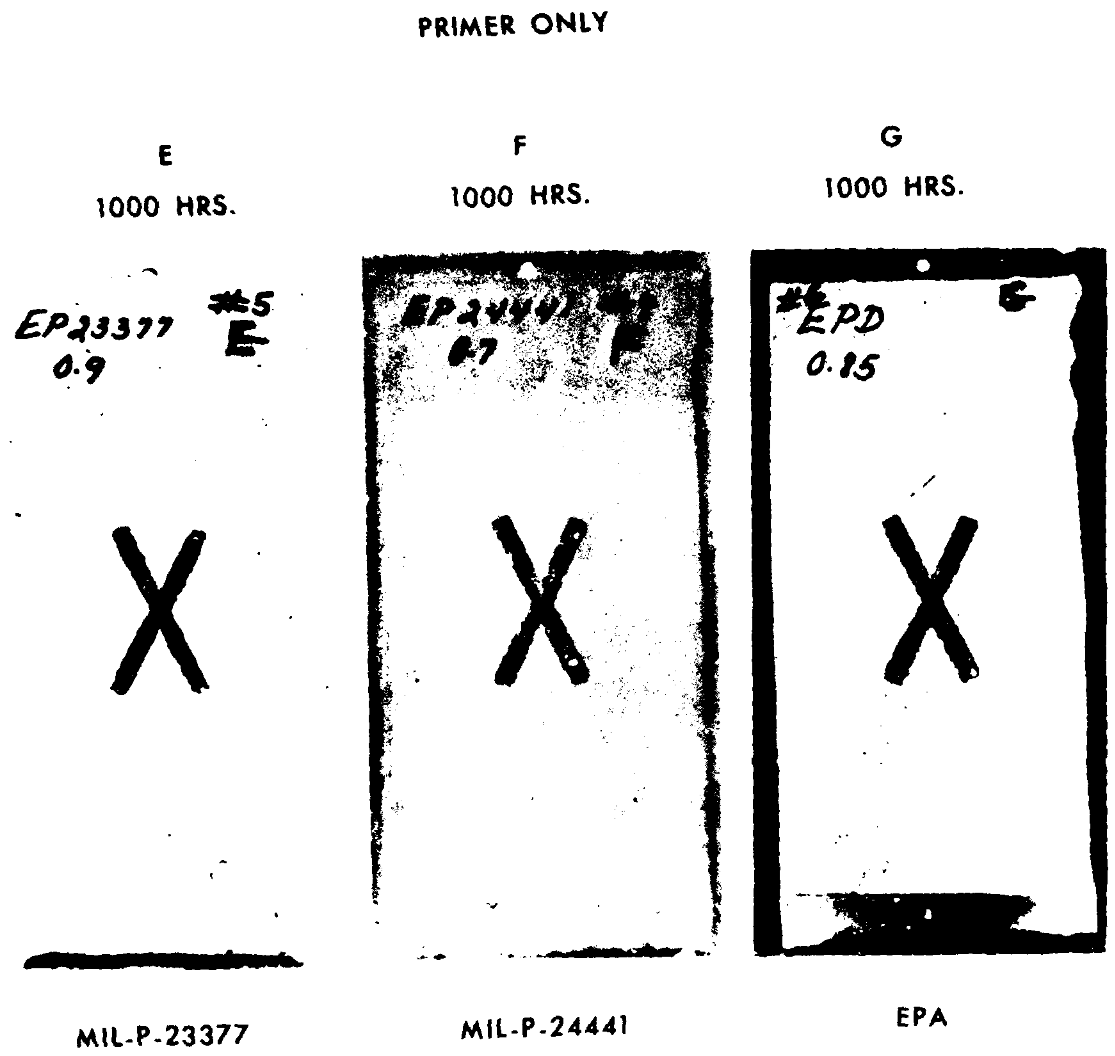


FIGURE 16. $NaCl-SO_2$ EXPOSURE TEST

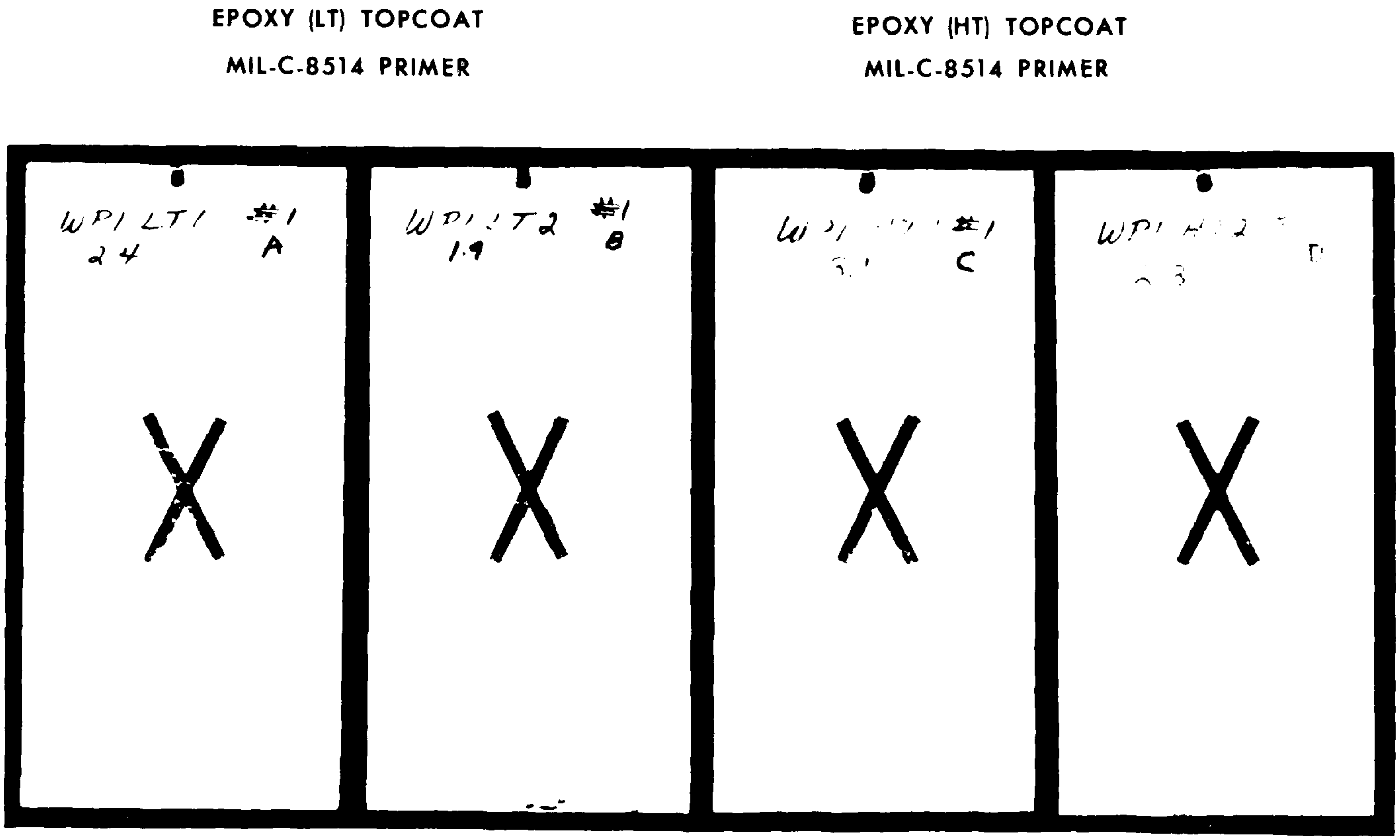


FIGURE 17. NaCl-SO_2 EXPOSURE TEST - 1000 HOURS

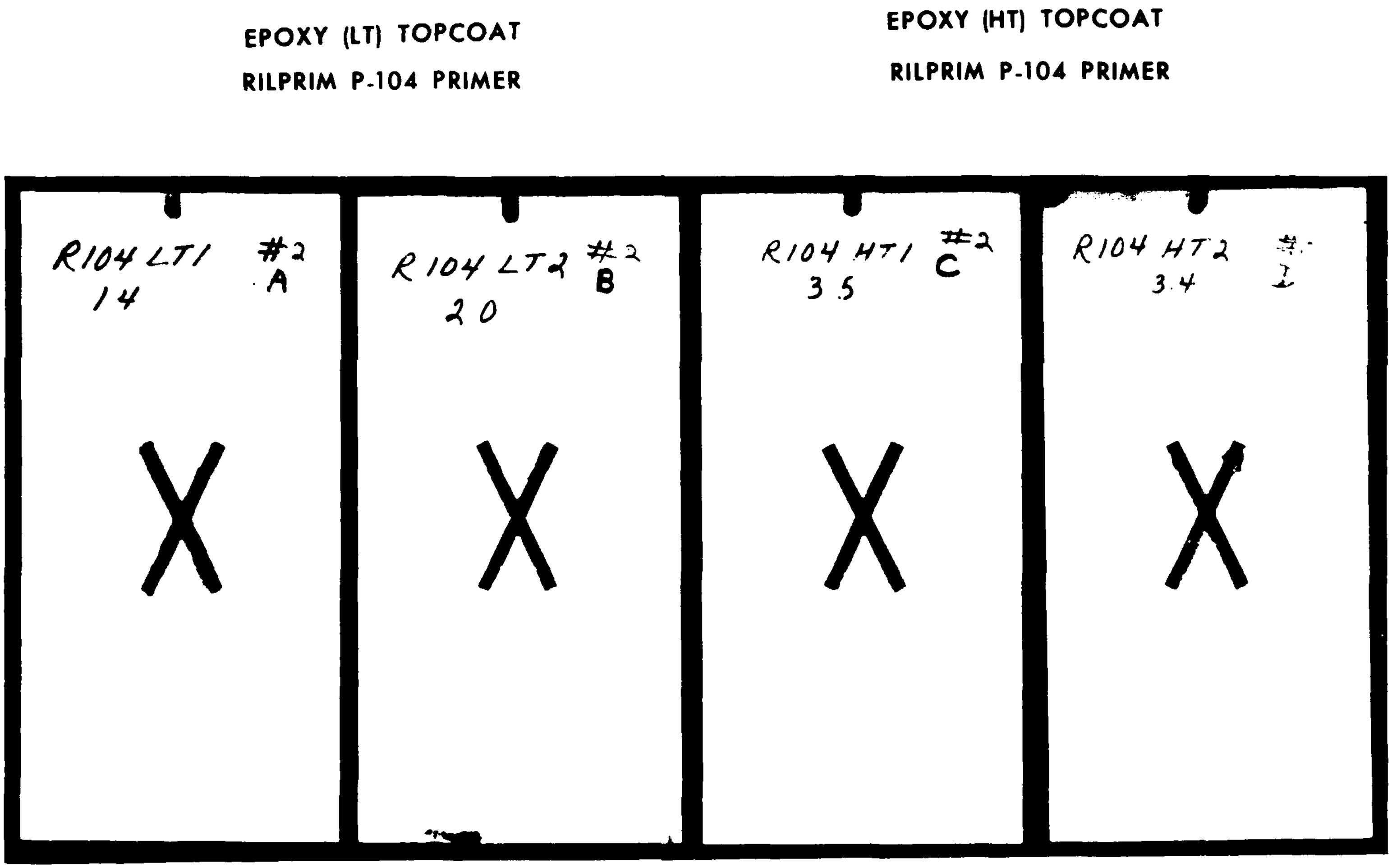
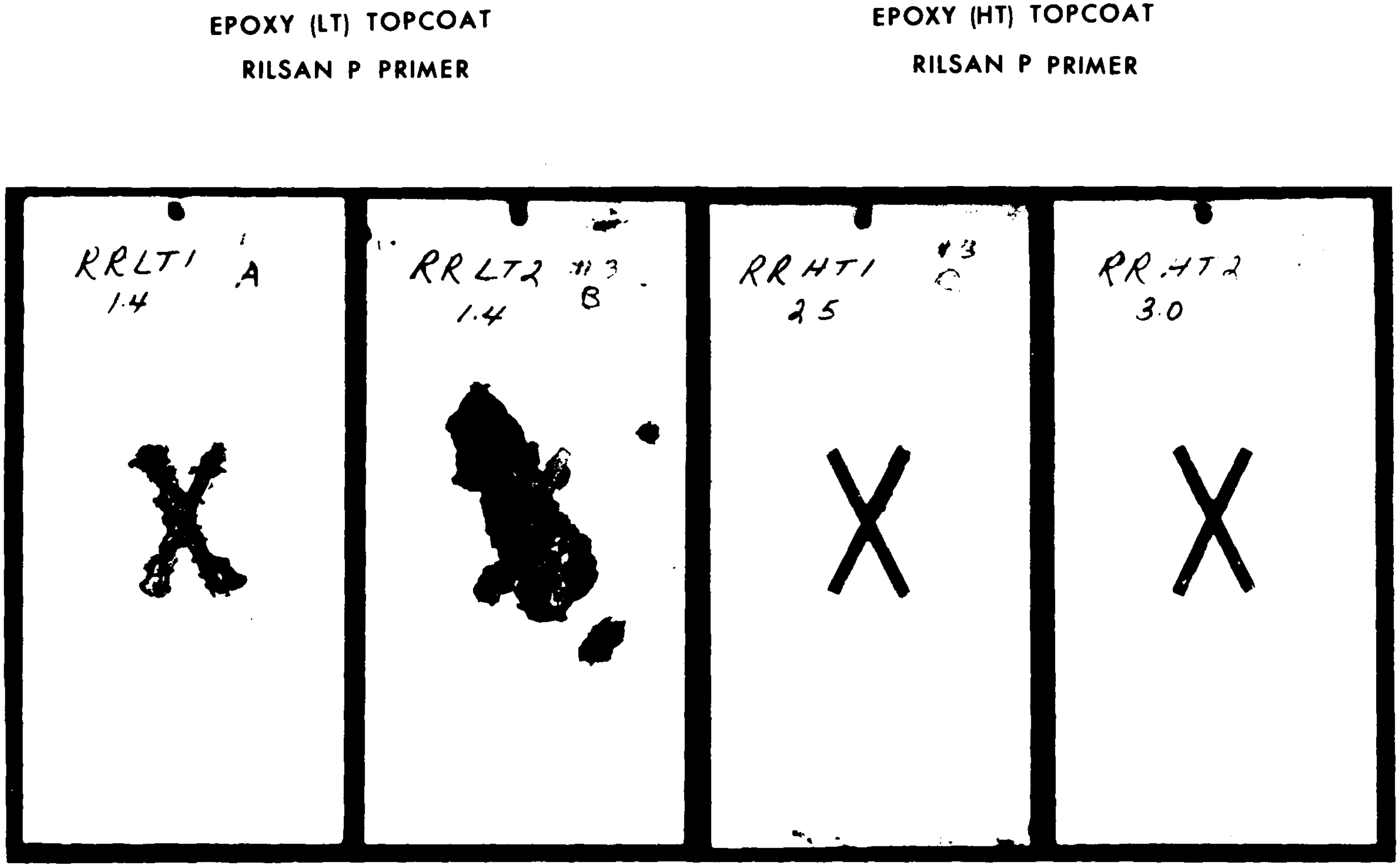


FIGURE 18. NaCl-SO_2 EXPOSURE TEST - 1000 HOURS



EPOXY (LT) TOPCOAT
RILSAN P PRIMER

EPOXY (HT) TOPCOAT
RILSAN P PRIMER

FIGURE 19. $NaCl-SO_2$ EXPOSURE TEST - 1000 HOURS

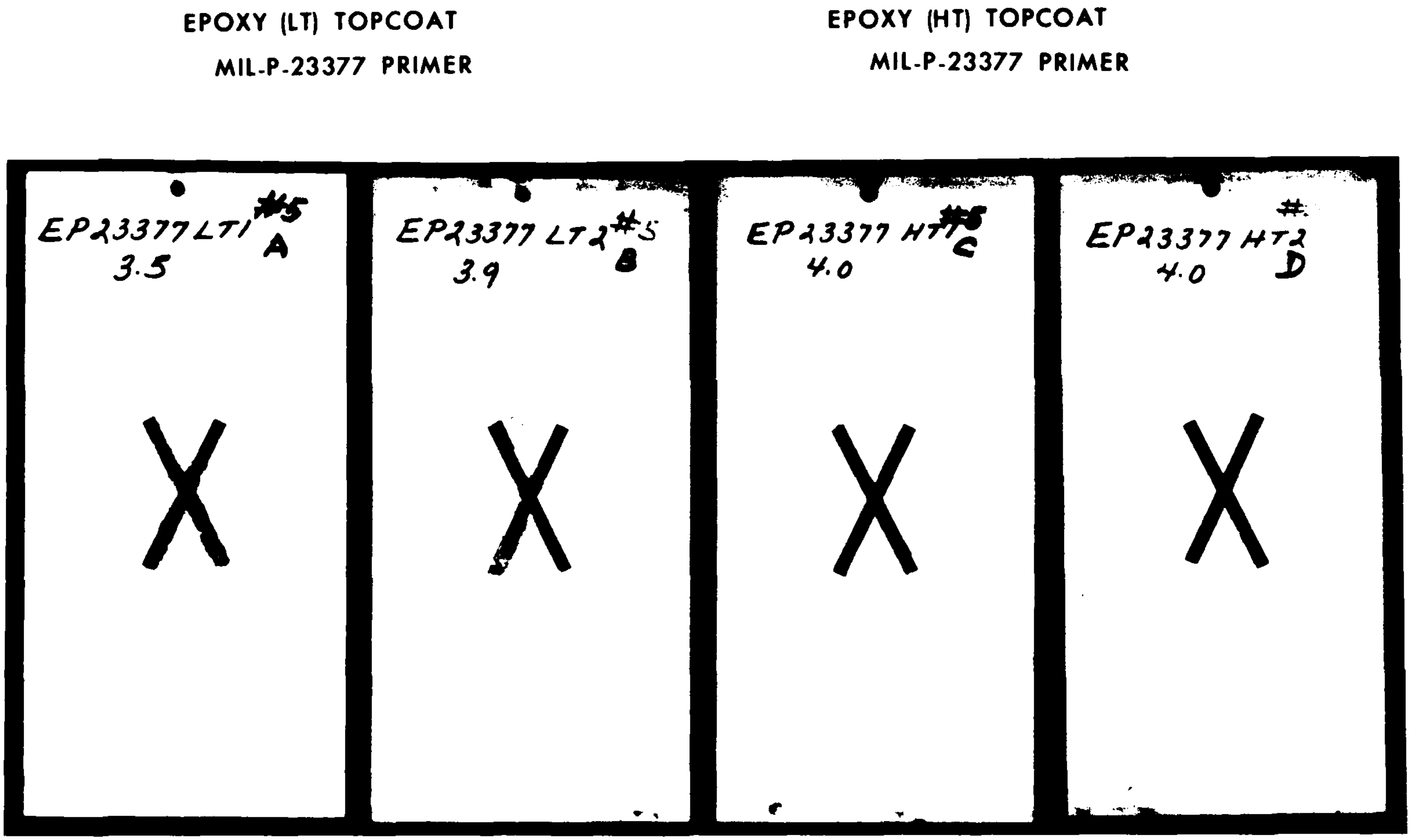


FIGURE 20. NaCl-SO_2 EXPOSURE TEST - 1000 HOURS

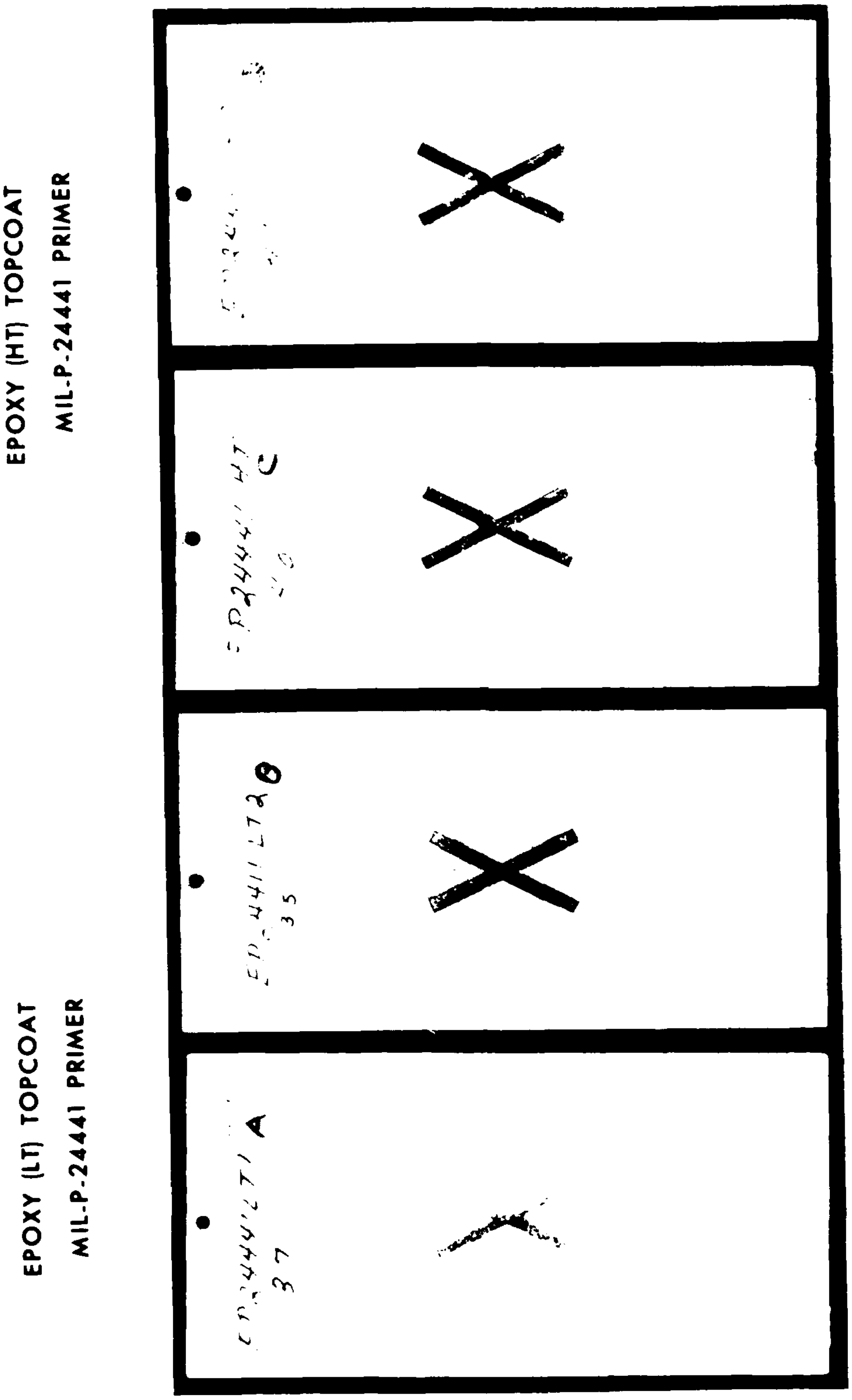


FIGURE 21. NaCl-SO_2 EXPOSURE TEST - 1000 HOURS

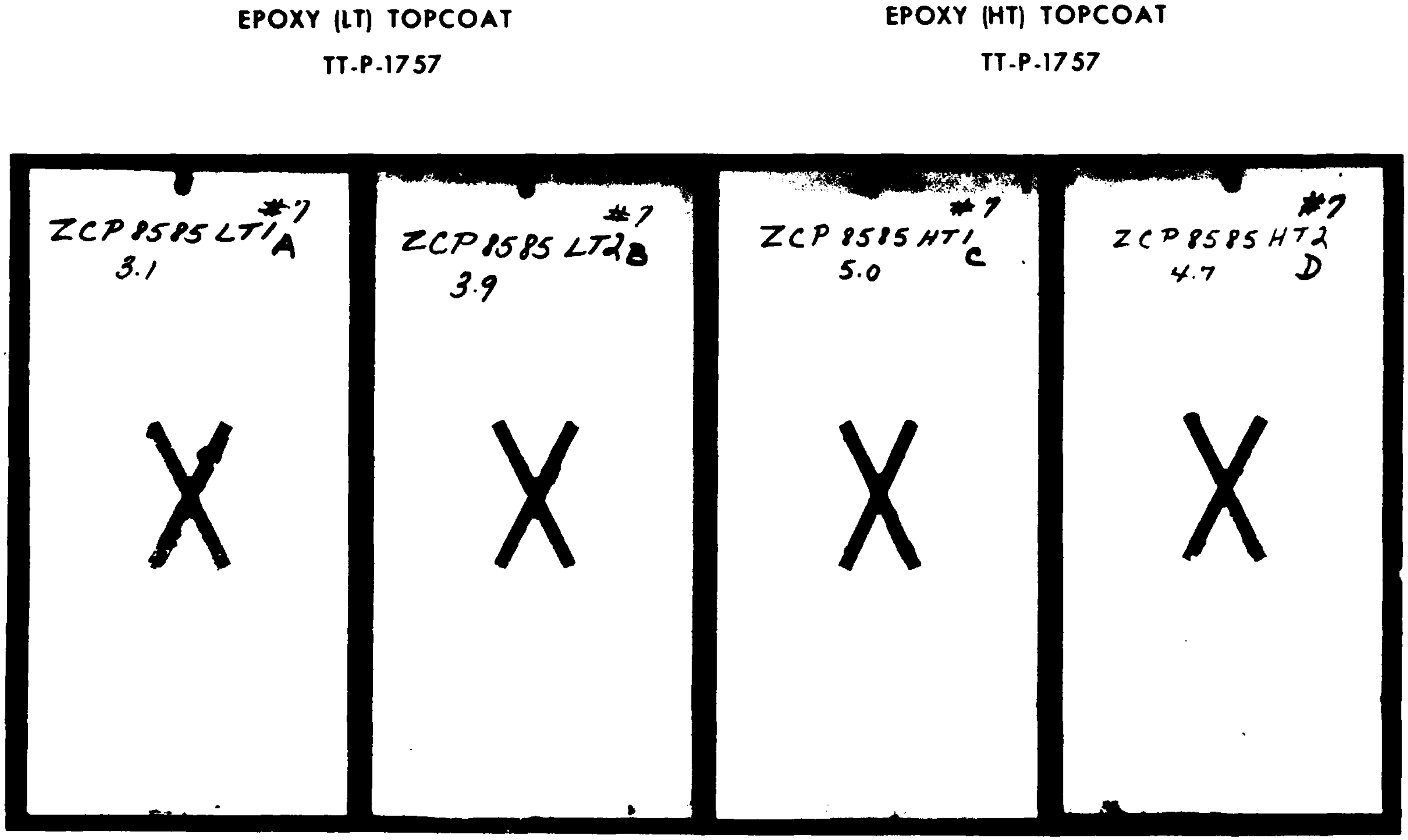


FIGURE 22. NaCl-SO_2 EXPOSURE TEST - 1000 HOURS

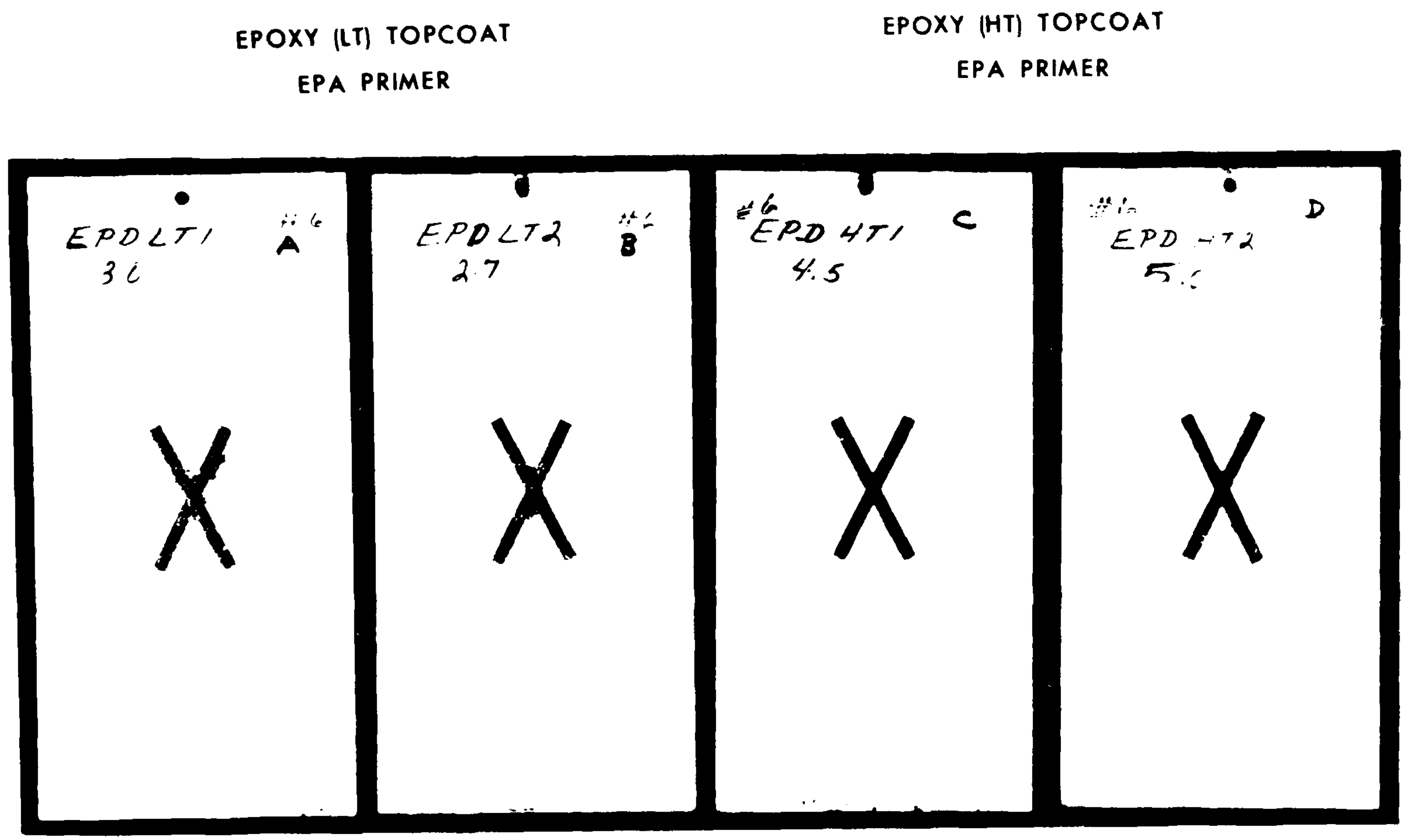


FIGURE 23. NaCl-SO_2 EXPOSURE TEST - 1000 HOURS

Figure 15 illustrates the condition of the MIL-C-8514, TT-P-1757, Rilsan P and Rilprim P-104 primers after the designated NcCl-SO_2 exposure periods. The epoxy polyamide primed panels MIL-P-23377 and MIL-P-24441 as well as the proprietary epoxy polyamine (EPA) primed panels, after the 1000 hour exposure period, are shown in Figure 16.

For testing purposes, a duplicate set of test panels was prepared for each primer that was topcoated with the selected epoxy (LT) and (HT) powder coating. This procedure was adopted in order to obtain test results based on powdered coatings applied at a different coating thickness.

When applying the high temperature (HT) chemical resistant and low temperature (LT) fast cure epoxy coatings to the MIL-C-8514 primed magnesium test panels, no coating failures were noted. The coated test panels illustrated in Figure 17 exhibited good adhesion and corrosion protection. Figure 18 illustrates the results of the same (LT) and (HT) epoxy coatings applied over the proprietary Rilprim P-104 primer. The results, after the 1000 hour exposure period, are comparable to the panels primed with the MIL-C-8514 illustrated in Figure 17. It should be noted here that both primers utilize a second component as the acid activator, the binder utilized in Rilprim P-104 being an epoxy phenolic, whereas MIL-C-8514 primer utilizes a polyvinyl butyrate resin as the pigment binder. MIL-C-8514 wash primer has been recommended highly in the coatings field as a good corrosion inhibitive primer for magnesium alloys. Figure 19 shows the results of the epoxy coatings applied over Rilsan P primer. Poor intercoat adhesion and corrosion protective properties were experienced utilizing the Rilsan P primer system topcoated with the low temperature cure (LT) epoxy coatings, whereas good adhesion and corrosion protective properties were obtained with the high temperature (HT) powder coating.

The results of the exposure studies when utilizing the Navy primer MIL-P-23377 (aircraft) and MIL-P-24441 (ships) were similar in that the (LT) epoxy topcoat failed the intercoat adhesion test on both primer systems, the MIL-P-24441 primed panels exhibiting a greater loss of intercoat adhesion. As experienced with the Rilsan P primed panels (see Figure 19), the (HT) epoxy topcoated panels did not show any coating failures. See Figures 20 and 21 for the epoxy primed and epoxy (LT) and (HT) topcoated panels subjected to the 1000 hour exposure test. Figures 22 and 23 demonstrate the coating properties of the (LT) and (HT) epoxy coatings applied over the Navy zinc chromate primer meeting Federal Specification TT-P-1757 and the proprietary amine cure epoxy (EPA) primer. Both epoxy powders, high temperature (HT) and low temperatures (LT), with the applied primer coats, protected the substrate magnesium with no intercoat failures.

To determine the effectiveness of primed substrates versus unprimed substrates, Figure 24 illustrates test panels that were topcoated without the use of a primer undercoat. Viewing Figure 24, it can be seen that the (LT) epoxy coated panel exhibits coating failure adjacent to the "X" scribe as well as pin point corrosion pits at random. The panel coated with the (HT) epoxy powder, however, exhibits good corrosion protective and adherent properties.

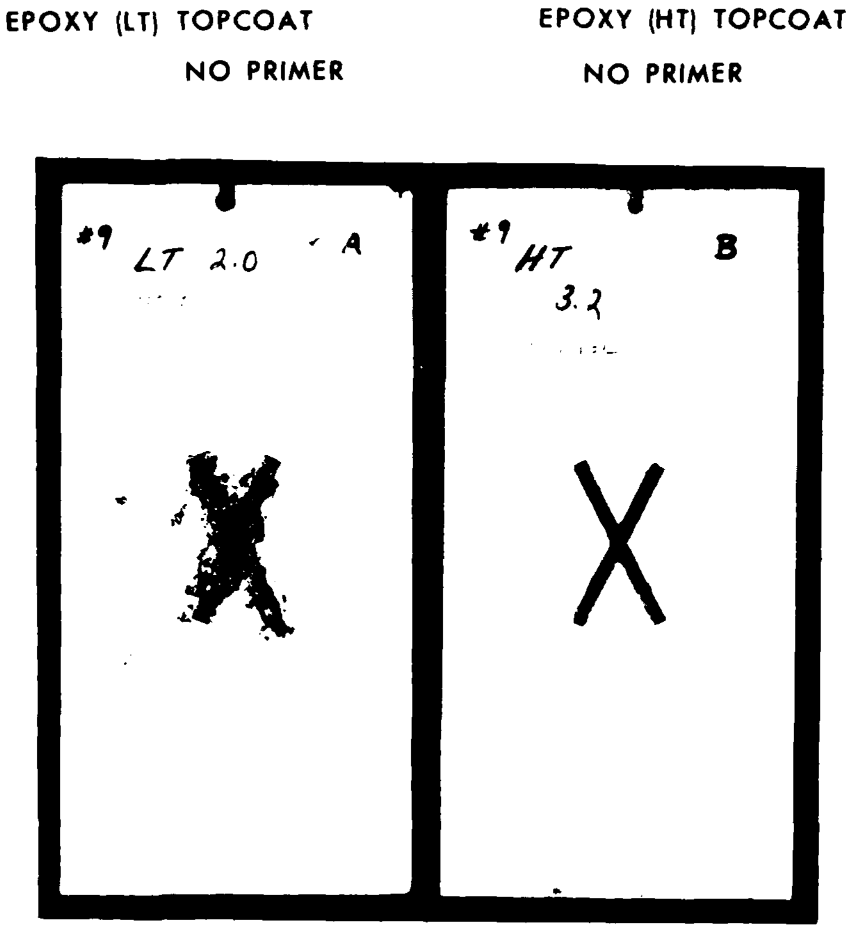


FIGURE 24. NaCl-SO_2 EXPOSURE TEST - 1000 HOURS

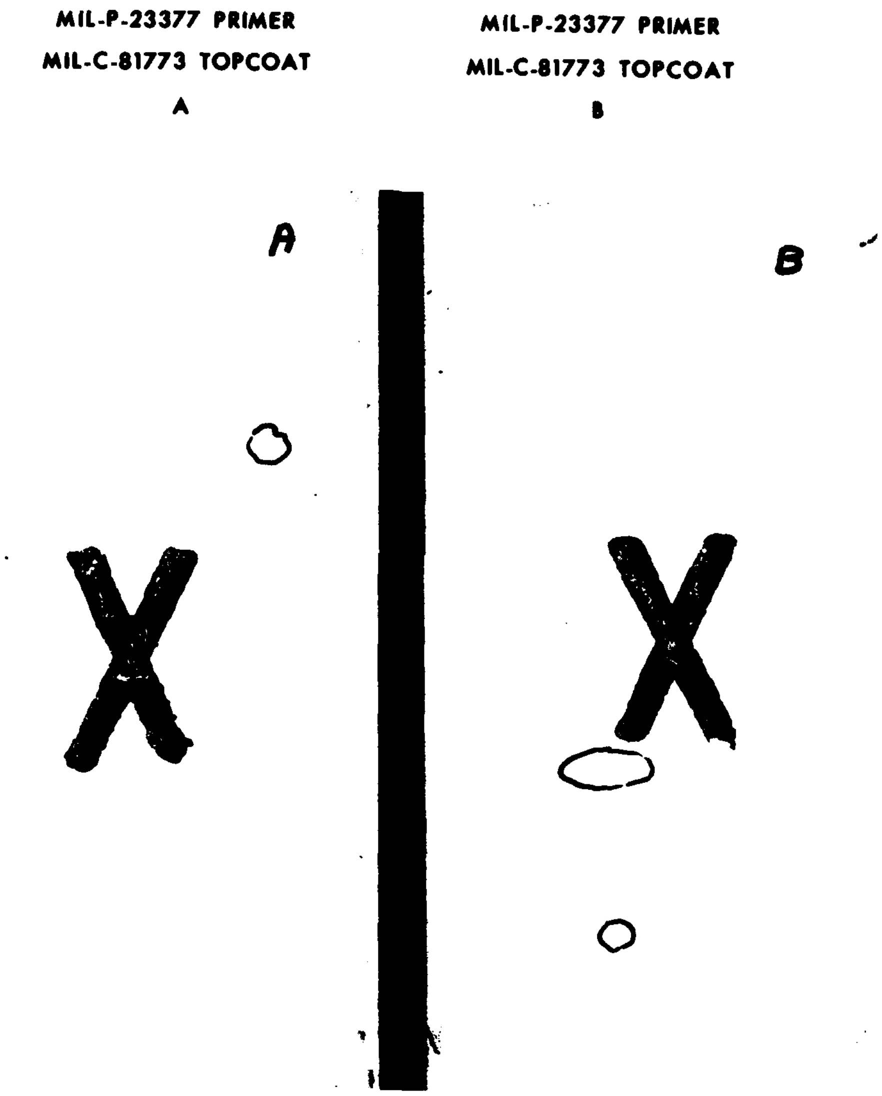


FIGURE 24 AB. $NaCl-SO_2$ EXPOSURE TEST - 1000 HOURS

OIL RESISTANCE TEST

The resistance of the powder topcoats to hot engine lubricating oils was obtained by immersing the coated panels in MIL-L-23699 lubricating oil at a temperature of 250 ± 4°F (121 ± 3°C) for a period of four hours. Two hours after removal from the hot oil, the panels were examined for blistering, film softening, discoloration and adhesion.

Additional chemical resistance tests were conducted on coated test panels immersed in hot MIL-H-83282 and Skydrol 500B hydraulic oils. The tests were conducted under the conditions as specified for the MIL-L-23699 lubricating oil. Specification MIL-H-5606 oil, a hydrocarbon based hydraulic oil was not included in the tests as specification MIL-H-83282 oil, a synthetic hydrocarbon based oil with higher temperature performing properties, is currently in the process of superseding MIL-H-5606 hydraulic oil.

Skydrol 500B, a proprietary hydraulic oil, was included in the test program to obtain data on the alkyl phosphate ester based hydraulic oil currently being utilized on most commercial aircraft and selected naval aircraft. The standard MIL-C-81773 coating systems, as with most solvent based coating systems, is severely attacked and removed by hot Skydrol 500B.

The powdered coatings, subjected to the hot engine and lubricating tests, were applied to both primed and non-primed 2024 clad aluminum test panels previously treated with a Class 1A chemical conversion coating meeting specification MIL-C-5541 requirements.

From the test results shown in Table VII, the cellulose acetate butyrate, vinyl and urethane coatings exhibited the poorest oil resistant properties as the coatings failed the MIL-L-23699 diester and Skydrol 500 tests.

The epoxy (LT) and epoxy (HT) chemical resistant coating, as well as the polyester coating, passed the lubricating (MIL-H-83282) and diester (MIL-L-23699) immersion tests. All three coatings, however, failed the Skydrol 500 test as the powdered coatings became soft and could easily be removed with a fingernail.

The polypropylene coating behaved differently in that the MIL-H-83282 fluid, being a hydrocarbon base lubricant, attacked and softened the non-polar thermoplastic coating applied to the base as well as the primed test panels. The polypropylene coating also failed the Skydrol test when applied to the base, MIL-P-23377 and epoxy polyamine (EPA) primed test panels. Suprisingly, however, the coating passed, in all cases when subjected to the diester oil MIL-L-23699 test.

The polyester powder coating, in all cases, passed the MIL-L-23699 diester oil and MIL-H-83282 lubricating oil test. The coating, however, failed in all circumstances to pass the Skydrol test.

The nylon powdered coating was superior in hot oil resistance properties to all of the coatings tested. Only two minor failures were noted. The coating, when applied to MIL-P-23377 epoxy polyamide and (EPA) epoxy

TABLE VII. HOT OIL RESISTANCE TEST DATA

Test No. 1. MIL-L-23699
No. 2. MIL-H-83282
No. 3. SKYDROL 500

Powdered Topcoat	Test No.	No Primer Coat	Primer Coatings - Solvent Based - Spray Applied				
			Rilsan P	Rilprim 104	MIL-P-24441	MIL-P-23377	EPA
Cellulose	1	F(3)	F(3)	F(3)	F(3)	F(3)	F(3)
Acetate	2	P	P	P	P	P	P
Butyrate	3	F(3)	F(3)	F(3)	F(3)	F(3)	F(3)
Epoxy	1	P	P	P	P	P	P
(LT)	2	P(1)	P(1)	P(1)	P(1)	P(1)	P(1)
	3	F(2)	F(2)	F(2)	F(2)	F(2)	F(2)
Epoxy	1	P	P	P	P	P	P
(HT)	2	P(1)	P(1)	P(1)	P(1)	P(1)	P(1)
	3	F(2)	F(2)	F(2)	F(2)	F(2)	F(2)
Nylon	1	P	P	P	P	P	P
	2	P	P	P	P	P	P
	3	P	P	P	P	F(2)	F(2)
Polyester	1	P	P	P	P	P	P
	2	P(1)	P(1)	P(1)	P(1)	P(1)	P(1)
	3	F(2)	F(2)	F(2)	F(2)	F(5)	F(5)
Polpropylene	1	P	P	P	P	P	P
	2	F(2)	F(2)	F(2)	F(2)	F(2)	F(2)
	3	F(4)	P	P	P	F(4)	F(4)
Urethane	1	F(2)	F(2)	F(2)	F(2)	F(2)	F(2)
	2	P	P	P	P	P	P
	3	F(2)	F(2)	F(2)	F(2)	F(2)	F(2)
Vinyl	1	F(2)	F(2)	F(2)	F(2)	F(2)	F(2)
	2	P	P	P	P	P	P
	3	F(2)	F(2)	F(2)	F(2)	F(2)	F(2)

Codes: F-Failed
P-Passed

(1) Slight discoloration (evident on white pigmented coatings).
(2) Coating softened (easily removed with fingernail).
(3) Coating dissolved.
(4) Coating blistered (topcoat).
(5) Very slight softening.

polyamine primers, softened slightly.

From tests conducted in the past, the standard Navy solvent based urethane coating system (MIL-P-23377 primer plus MIL-C-81773 urethane topcoat), passes the MIL-H-83282 lubricating oil and MIL-L-23699 engine oil test, but fails the Skydrol 500 test. (See reference (a) report.)

It can be concluded, therefore, that:

1. The nylon coating, in all cases, and the polypropylene coating, in specific cases, are superior to the standard Navy coating system when subjected to the severe hot Skydrol 500 test, and

2. Powder coatings applied over a protective primer system yield coatings with hot oil resistance properties equal or superior to the same coating applied to the bare aluminum substrate.

S. S. WHITE ABRASION TEST

Experimental testing was performed on the S.S. White Abrasive Jet Unit, Model K. The method utilized to obtain the abrasion test data is described in reference (b). All of the tests were conducted using the following fixed variables: type and diameter of orifice, type of abrasive used, distance between the orifice and test panel, force propelling the abrasive and powder flow setting. A propelling force of 60 psi was selected in order to obtain the maximum amount of abrasion and test data which could be correlated with tests conducted in the past.

An attempt was made to obtain coating specimens within an approximate film thickness and at a film thickness that is within the design limits for aircraft and engine component parts. Therefore, the powder coatings were applied to test panels within a film thickness range of three to six mils (0.076 to 0.152 mm). Also, controlling the film thickness within a limited range assures, somewhat, that abrasion results will be reasonably linear with film thickness. The substrate utilized as the test panels was 3 x 6 x 0.020 in. (7.62 x 15.24 x 0.05 cm) 2024 clad aluminum alloy chemically pretreated with MIL-C-5541, Class 1A chemical conversion coating.

All of the powdered topcoats, as well as the standard Navy MIL-C-81773 solvent based urethane topcoat, were applied directly to the pretreated aluminum test panels. For the abrasion test studies, the primer coats were not included as part of the coating system for the following reasons:

- The abrasion tests were conducted mainly to obtain the wear properties of the topcoats, and

- The time in seconds required to penetrate to the substrate metal on thin coatings, can be more accurately detected when the primer coat is omitted.

An average of five penetration tests were made and an average of three film thickness determinations were taken within 1/2 in. (1.27 cm) from each abrasion test site. The testing instrument used to obtain the film thickness measurements was the Permascope. The time required to abrade the film down to the metal substrate was divided by the film thickness to obtain the film abrasion efficiency. The individual tests, average time, film thickness and abrasion efficiency values are represented in Table VIII.

The accuracy of time (T) in seconds to abrade the film was reproducible and accurate, as the variations of individual determinations never exceeded ten percent of the average for any individual specimens. The accuracy in timing the end point (failure to substrate) was made possible through the use of a Lab-Chron Timer which recorded the penetration time within a tenth of a second. A Bausch and Lomb light, equipped with a five inch diameter (12.7 cm) 10X lens, was utilized to visually detect the coating as erosion progressed to the substrate.

The coating systems and the resultant S.S. White test data listed in Table VIII illustrates that the three coatings exhibiting superior abrasion resistant properties are nylon, polypropylene and clear urethane. The white pigmented epoxy, polyester, urethane and cellulose acetate coatings approximate the abrasion resistance properties of the standard solvent based two-component linear urethane coating meeting MIL-C-81773B requirements. The green vinyl coating gave the poorest abrasion resistance value of the coatings tested.

Figure 25 shows test panels that were subjected to the S.S. White abrasion test. The time in seconds to penetrate the coating, as the tests were being conducted, are recorded adjacent to each test site.

STRIPPABILITY TEST

The removability of paint systems from metallic substrates is unpredictable. Many factors are involved, such as the application procedure, curing temperature, treatment of substrate metal before application of the paint system and selection of primer finish.

In most instances, especially on exterior surfaces of aircraft and on engine and aircraft component parts, the ease in which the protective coating can be removed to properly inspect, overhaul and repair the item, is most essential to extending the life cycle of weapon systems.

Most coatings currently utilized on naval weapon systems can be removed using specification MIL-R-81294 paint stripping compound. The highly alkaline stripper readily removes the urethane MIL-C-81773 topcoat as well as the MIL-P-23377 epoxy polyamide primer finish. A dwell time of approximately 10 to 15 minutes is all that is required to allow the MIL-R-81294 stripper to penetrate and break the coating from the aluminum substrate.

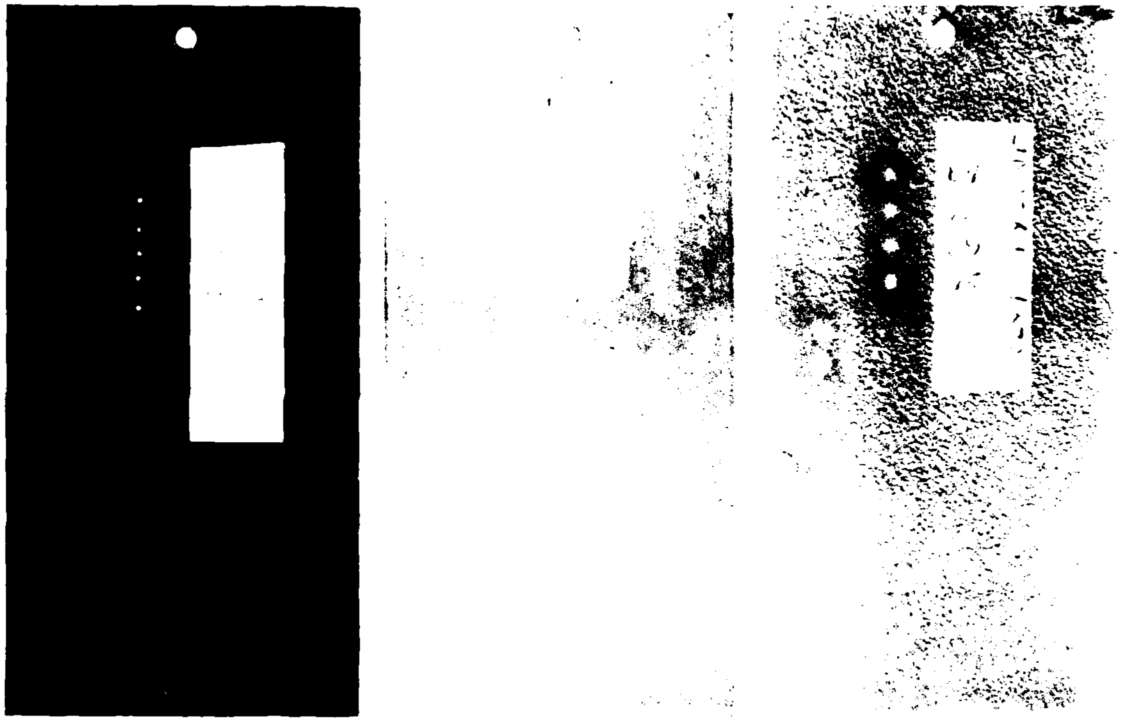
Therefore, to obtain comparable test data, the powdered coatings, applied over three different primer systems, were subjected to the MIL-R-81294

TABLE VIII. ABRASION RESISTANCE TEST DATA

S.S. WHITE (MODEL K) - ABRASIVE NO.10) - POWDER FLOW AT 60 PSI (413.7 kPa) PRESSURE

Applied Coatings	T (Time in Seconds to Penetrate) Individual Determinations					T (Avg)	Film Thickness Avg (Mils)	Abrasion Efficiency (Sec/Mil)
CAB (Black) Cellulose Acetate Butyrate	10	10	11	11	11	10.6	5 (0.127μm)	2.10
LT (White) Fast Cure Epoxy	2.6	2.5	2.8	2.8	2.8	2.7	3.2 (0.081μm)	0.85
HT (White Chem. Resist. Epoxy	5.9	5.3	5.3	5.8	5.5	5.6	4.0 (0.100μm)	1.40
N (Natural) Nylon	38	37	34	38	36	37	3.8 (0.096μm)	9.74
N (Red) Nylon	48	47	43	50	48	47	5 (0.127μm)	9.40
PE (White) Polyester	4.0	3.5	4.0	4.0	3.4	3.8	3 (0.076μm)	1.26
PP (Blue) Polypropylene	67	72	69	75	67	70.0	5.5 (0.140μm)	12.73
UR (White) Urethane	2.6	2.5	2.6	2.5	2.5	2.5	3.2 (0.081μm)	0.79
VL (Green) Vinyl	5.0	7.0	6.0	6.0	6.0	6.0	3.4 (0.087μm)	1.76
Control (White) (X) MIL-C-81773	3.0	3.1	2.9	2.9	3.0	3.0	2.8 (0.071μm)	1.07

(X) Solvent Based Linear Urethane



CELLOSOLVE ACETATE BUTYRATE **NYLON** **POLYPROPYLENE**

FIGURE 25. S.S. WHITE ABRASION TEST - NO PRIMER COAT

strip test as follows:

a. One half of the topcoated test panels were covered with a paint remover conforming to the requirements of MIL-R-81294.

b. The paint stripper was allowed to dwell for a 15, 30 or 60 minute time period, whichever period was required to soften the coating to a removable condition.

c. Upon completion of the test period, the panels were scrubbed lightly (10 passes) with a nylon brush.

d. The panels were then rinsed with a stream of cold water to remove any loosened paint, and examined.

Table IX illustrates the applied coatings, dwell times and stripping results. The powdered cellulose acetate butyrate and vinyl topcoats were readily removed after a dwell time of 30 minutes. The primer coats, however, remained intact. The nylon topcoat became soft and peeled from the primer coats after being exposed to paint stripper for one hour. The LT and HT epoxy topcoats, as well as the polyester and urethane powdered topcoats, all behaved in the same manner, being softened by the stripper but remaining intact as a coating system. The only powdered coating that was not softened by the organic stripper was polypropylene, exhibiting excellent resistance to the highly alkaline MIL-R-81294 stripper, and therefore exhibiting poor strippable properties.

TABLE IX. STRIPPABILITY TEST DATA

Organic Stripper - MIL-R-81294 Conditions - Room Temperature

Applied Topcoats	Applied Primer Coats	Dwell Time (Min.) 15	30	60	Condition of Coating
Cab (Black)	MIL-P-23377	CS	R	-	Removed to Primer Coat
Cellulose Acetate	Rilsan-P	CS	R	-	Removed to Primer Coat
Butyrate	Rilprim-104	CS	R	-	Removed to Primer Coat
LT (White)	MIL-P-23377	NC	NC	S	SL Removed to Substrate (STK)
Fast Cure Epoxy	Rilsan-P	NC	NC	NC	Intact (STK)
	Rilprim-104	NC	NC	NC	Intact (STK)
HT (White)	MIL-P-23377	NC	NC	S	SL Removed to Substrate (STK)
Chem. Resist.Epoxy	Rilsan-P	NC	NC	NC	Intact (STK)
	Rilprim-104	NC	NC	NC	Intact (STK)
N (RED)	MIL-P-23377	NC	S	S	Removed to Primer Coat (STK)
Nylon	Rilsan-P	NC	S	S	Removed to Primer Coat (STK)
	Rilprim-104	NC	S	S	Removed to Primer Coat (STK)
PE (White)	MIL-P-23377	NC	NC	NC	Intact (STK)
Polyester	Rilsan-P	NC	NC	NC	Intact (STK)
	Rilprim-104	NC	NC	NC	Intact (STK)
PP (Blue)	MIL-P-23377	NC	NC	NC	Intact (HTK)
Polypropylene	Rilsan-P	NC	NC	NC	Intact (HTK)
	Rilprim-104	NC	NC	NC	Intact (HTK)
UR (White)	MIL-P-23377	NC	S	S	Intact (STK)
Urethane	Rilsan-P	NC	S	S	Intact (STK)
	Rilprim-104	NC	S	S	Intact (STK)
VL (Green)	MIL-P-23377	CS	R	-	Removed to Substrate
Vinyl	Rilsan-P	CS	R	-	Removed to Substrate
	Rilprim-104	CS	R	-	Removed to Substrate
(X) Control (White)	MIL-P-23377	R	-	-	Removed to Substrate
MIL-C-81773					

(X) Solvent Based Linear Urethane.

Codes:
CS (Coating Solubilized to Substrate)
S (Coating Softened)
NC (No Visible Change)
(STK) Soft to Plastic Knife
(HTK) Hard to Plastic Knife
R (Coating Removed)

REFERENCES

(a) Evaluation of Soil Resistant Coatings for Exterior Aircraft Surfaces, NAVAIRDEVCEN Report No. NADC-77182-30, Jun 1977

(b) Synthesized Ketimine A Replacement Curing Agent for MOCA, NAVAIRDEVCEN Report No. NADC-76038-30, Jan 1976

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