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TECHNICAL REPORT

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IMPROVED COATING SYSTEM FOR HIGH STRENGTH TORSION BARS

Final Report
23 April 1981

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Endurance Test	Organic Coating	

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Eight candidate coatings were selected during Phase I and tested in comparison to the current tape and primer system used on the body section of suspension torsion bars. Laboratory tests involving coated panels and one-third length torsion bars were employed in determining the most cost-effective candidate.

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ABSTRACT

Production M113A2 torsion bars were coated with the selected product during Phase II and life tested in comparison to the current system. Each group of bars was subjected to a standard damage/corrosion method prior to endurance testing. A statistical analysis of bar life data quantified the increased protection level afforded by the Improved Coating System.

PREFACE

This project, which has as its objectives to cost effectively improve service life of suspension torsion bars and reduce the number of bar rejections due to corrosion, was authorized under Contract DAAK30-80-C-0004 by U.S. Army Tank-Automotive Command (TACOM), Warren, Michigan, with Mr. Kazys Navasaitis serving as Technical Supervisor. Contractual work was conducted by FMC Corporation, Ordnance Engineering Division, San Jose, California. Laboratory investigations and test work were performed at the FMC Corporation Materials Engineering Laboratory, Santa Clara, California. Contract period was 23 January 1980 to 23 April 1981. This is the final report covering all work conducted under this contract.

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OBJECTIVE

The objective of this program was to develop a coating system for the torsion bar body section which will cost effectively improve the service life of high strength torsion bars and at the same time reduce the number of torsion bar rejections due to corrosion. The level of protection afforded by the present tape and primer coating system was determined and is used for comparison.

INTRODUCTION

All current tracked military vehicles in the U.S. inventory, including the M1 Main Battle Tank and the M2 Infantry Fighting Vehicle, use high-strength torsion bar springs in their suspension systems. Recent improvements in vehicle cross-country mobility have been achieved in large part by increasing roadwheel travel and developing torsion bars capable of operating at higher stress levels. As a result, bars have become more sensitive to surface damage such as that caused by corrosive pitting or damage that occurs when tools or other objects accidentally strike a bar during vehicle maintenance or repair operations.

The method of protecting high strength suspension torsion bar springs is set forth in MIL-S-45387 which specifies that a coating of primer paint be applied directly to the precleaned body of the steel bar (but not on the splines), followed by a spirally wound layer of self-adhesive polyethylene tape, applied with a 50% overlap. This provides a double layer of tape to resist abrasion and protect the primer paint from damage. Experience has proven that this tape/primer system does not provide adequate protection against the environment to which bars are normally exposed.

Torsion bars are located in the bilge area near the hull bottom plate. Diesel fuel, oil, water, and other liquids that may leak into the engine or crew compartment from vehicle swimming or cleaning operations run into the bilge where they come in contact with torsion bars. Diesel fuel (a hydrocarbon) has been found to attack tape adhesive, causing loss of tape integrity and exposing the primer paint to moisture and abrasive damage. Maintenance personnel sometimes walk on torsion bars or accidentally drop tools or vehicle parts onto them. Figure 1 shows an example of deterioration of the protective tape wrapping caused by diesel fuel that had leaked into the bilge and by abrasion from personnel walking on torsion bars.

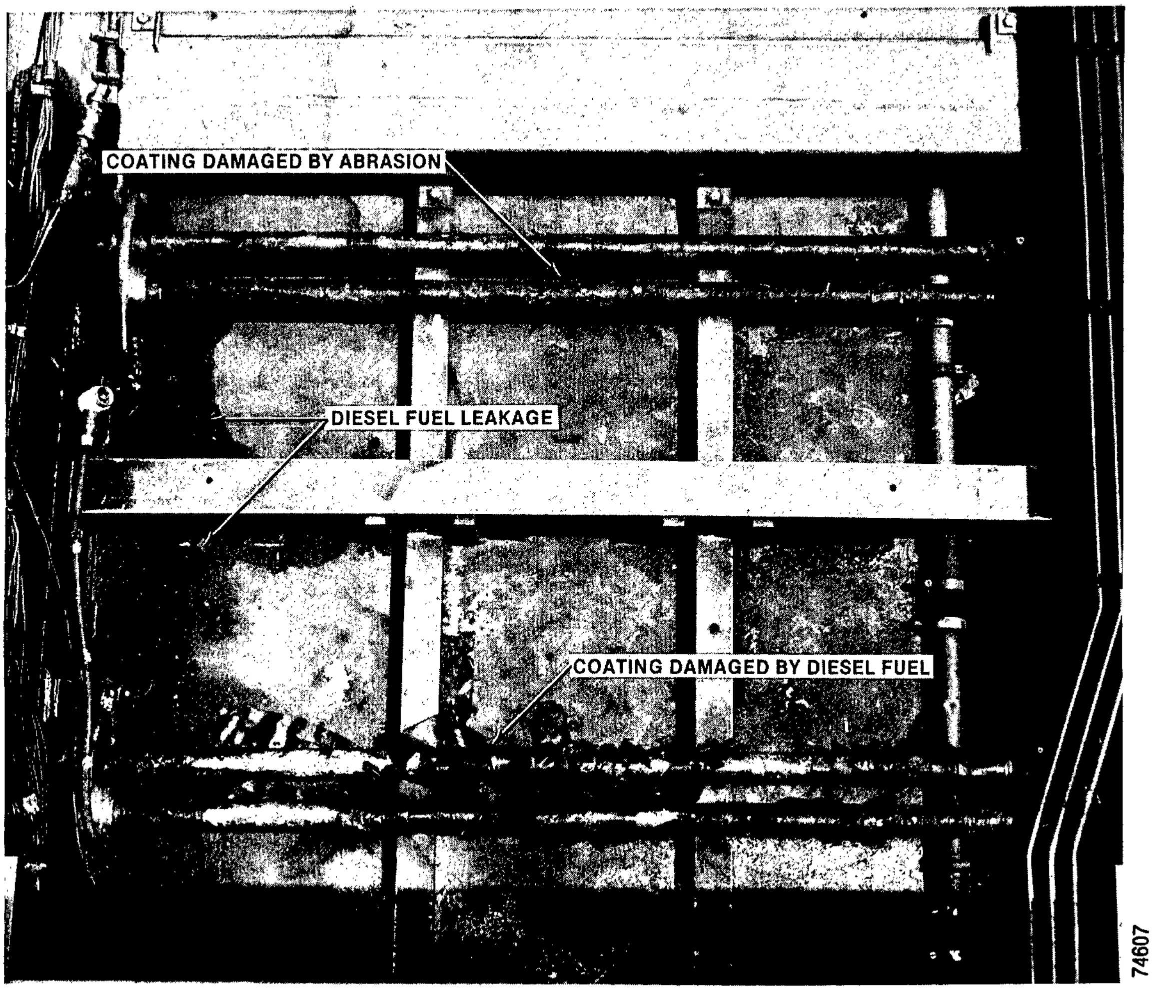

Figure 1. Degradation of Torsion Bar Protective Tape Coating in M730 Vehicle (M113 Family) Bilge Resulting from Abrasion and Contact with Diesel Fuel.

Although inhibitive pigments in the red oxide or zinc chromate primer (type is optional in the specification) offer the steel torsion bar some degree of corrosion protection, paint adhesion deteriorates after extended contact with moisture, permitting corrosive attack on the torsion bar surface. The combination of corrosion and continual stresses tends to propagate corrosion pits into cracks. These flaws become fracture initiation sites and can lead to premature bar failure. If corroded areas are detected during maintenance inspections, the affected bar is removed from service before failure can occur.

TECHNICAL APPROACH

This program was divided into two phases with implementation of the second phase contingent upon successful completion of the first. Phase I consisted of the selection of test methods, and laboratory testing of the current tape and primer system and eight candidate coatings that had been applied to test panels. Next, one-third length torsion bars coated with tape and primer and the two most promising candidate coatings were endurance tested. In each case, test bar coatings had been subjected to an equal degree of impact energy and equal exposure to a corrosive environment prior to endurance testing. Performance of uncoated, undamaged bars was determined and used as a baseline for comparison. Cost factors were applied to determine the two most cost effective coatings. A reliability analysis using Weibull techniques was performed to determine the degree of improvement afforded by the candidate coatings.

During Phase II, the coating that was determined to be the most cost effective in Phase I was applied to M113A2 production torsion bars and life tested. Results were compared to test results for bars coated with tape and primer to verify the degree of improvement in life that had been achieved. Each bar had been presubjected to an equal exposure to corrosive environment. Weibull techniques were applied to test results to determine the degree of improvement that had been achieved. In addition, several M48/M60 tank bars were coated with the Improved Coating System to verify coating application methodology on the largest torsion bars in the military system.

To assure producibility, coating application specifications and quality assurance requirements for the Improved Coating System were developed in concert with the coating application vendor.

PHASE I

Selection of Coating for Test

To evaluate state-of-the-art methods for preventing corrosion of steel, a review of coating methods and commercially available products was performed by the Coating Section of the FMC Materials Engineering Laboratory. To assist in screening the large number of potential coating candidates and reducing them to a reasonable group for detailed investigation, the functional requirements of this application were reveiwed. It was determined that a successful high strength torsion bar body coating should exhibit the following characteristics:

- Good adhesion to steel
- Corrosion resistance
- Hydrocarbon resistance
- Flexibility
- Abrasion resistance
- Impact resistance
- 350° F maximum process temperature so that processing will not affect bar temper
- Cathodic protection if a metallic coating.

After an analysis of the specifications and cost data provided by vendors and discussions with their technical personnel regarding application methods and equipment requirements, it was determined that the following types of coatings offered the most promise for this application.

- Metallic coatings, which provide cathodic protection as a means of preventing or reducing corrosive attack on the steel torsion bar surface at a damage site.

- Inorganic and organic metal filled coatings, which afford some degree of cathodic protection to the steel surface at a damage site.

- Plastic coatings of a resilient nature, which protect by preventing moisture or corrosives, from contacting the steel surface, and which have excellent mechanical damage resistance.

One or more of each coating type was selected for evaluation during the initial laboratory investigation during Phase I. A description of these candidates (with coating type indicated) follows:

1. IVADIZE (metallic coating) - An ion vapor-deposited coating of pure metallic aluminum applied by a patented process, owned by McDonnel Aircraft Company, St. Louis, MO. Specialized equipment required includes a vacuum chamber, pumping system, evaporization source, and high voltage power supply. A typical deposition cycle requires 45 minutes and applies 1 to 2 mils of aluminum. Torsion bar temperature reportedly does not exceed 200° F during the application process. The deposition process does not produce hydrogen embrittlement within high strength steels and therefore does not require a postbake cycle.

2. DACROMET 320 (inorganic metal filled coating) - An inorganic immersion coating composed primarily of chromium, proprietary organics, and zinc flakes which provide a metallic silver color. This patented coating is owned by the Diamond Shamrock Corporation, Chardon, OH, and can be applied by spraying, dipping, or brushing. Hydrogen embrittlement does not occur in high strength steels during the application process. A normal oven curing temperature for Dacromet 320 is 575° F for 8 minutes. A much longer cure time is necessary at the 350° F cure temperature limit imposed by this application. Coating thickness is typically 0.2 to 0.3 mils.

3. CARBOZINC SP 81 (inorganic metal filled coating) - A zinc rich inorganic coating of a generic type that is offered by several manufacturers. Carbozinc SP 81 is a product of the Carboline Company, St. Louis, MO and can be applied by spraying, dipping, or brushing. No oven cure is required and there is no danger of hydrogen embrittlement. Coating thicknesses generally range from 3 to 5 mils.

4. ALUMAZITE Z (organic metal filled coating) - An aluminum filled organic coating produced by the Tiodize Company, Huntington Beach, CA that can be applied by spraying, dipping, or brushing. The normal cure temperature is 400° F which could be reduced to 350° F by increasing the oven cure time. Hydrogen embrittlement is not generated during the cure. Recommended coating thickness is 0.2 to 0.6 mils.

5. PLASTISOL (plastic coating) - This generic term is used to describe the fluid mixture of polyvinyl chloride resins together with curing and stabilizing agents. It is formulated by several manufacturers and displays excellent resistance to abrasion, has high tensile strength, has resistance to hydrocarbons and moisture, and has long term stability. A

single part, air drying primer, must be applied to steel surfaces to obtain adhesion. Plastisol can be applied by dipping, spraying, or rolling. Only the dip method was used in this program. A temperature of 325° F for about 15 minutes is required for curing. A general use type of Plastisol and a fungus resistant type are specified in MIL-P-20689, Plastic Plastisol (For Coating Metallic Objects). Plastisol coatings for this program were applied by Production Engineering, Inc., San Rafael, CA. Coating thicknesses from 10 to 60 mils can be achieved depending upon the application method.

6. ELASTUFF 504 POLYURETHANE (plastic coating) - A highly cross-linked, two-component, thermosetting polyurethane rubber manufactured by United Coatings Company, Spokane, WA, that can be applied by airless or air atomizing spray equipment. It exhibits good resistance to hydrocarbons and moisture, and good mechanical damage resistance. Steel surfaces must be primed with a two-component polyvinyl-polyurethane primer. Up to 40 mils can be applied in one coat using multiple passes. Elastuff 504 dries in one hour at room temperature.

7. ELASTUFF 701 POLYURETHANE (plastic coating) - This product, also manufactured by United Coatings Company, and differs from Elastuff 504 only in that it has an extremely short drying time of three minutes. It must be applied with plural component spray equipment which mixes the two components within the spray head. Because of the 10-second gel time, a heavy coating thickness can be built up in one multiple pass application.

8. INJECTION MOLDED POLYURETHANE (plastic coating) - Is a two-component, injection molded, thermosetting elastomer compounded to produce a tough, dense, flexible urethane completely free of the minute bubbles (microcellular structure) generally present in sprayed urethanes. This new process was developed by

Production Engineering, Inc., San Rafael, CA, and requires a two-minute low temperature cure within the mold. Coating thickness can be varied as desired. A method utilizing a split mold would be required to apply this coating to the torsion bars.

Initial Laboratory Investigation

At the onset of this work, an analysis of the environmental and operational conditions that a vehicle-installed torsion bar must withstand was made in an effort to select the individual tests to which candidate coatings should be subjected. It was determined that coating damage could be divided into two categories:

- Contact with liquids
- Mechanical means

Liquids that may affect the coating include diesel fuel, engine lubrication oils, and water. Diesel fuel and engine oil (hydrocarbons) enter the bilge through system leakage or spillage. Water enters during swimming operations, when a vehicle is cleaned (sometimes with steam), or from rain. Liquids can accumulate in bilges of parked vehicle and remain in continuous contact with torsion bars for long periods of time.

Mechanical damage includes surface abrasion resulting from maintenance personnel walking on exposed torsion bars, surface abrasion caused by hoses or tubing rubbing against torsion bars, surface abrasion that occurs when torsion bars slide over sharp hull edges during installation or removal, and impact damage from tools or vehicle parts that are accidently dropped on torsion bars.

The initial laboratory investigation section of Phase I was designed to evaluate the corrosion protection afforded by the present MIL-S-45387 tape and primer coating system (as a baseline), while simultaneously determining the effectiveness of each candidate coating.

To accomplish this objective the eight coatings selected, plus the tape/primer system, were applied to seven standard 0.030-inch thick type R-412 steel panels (56 panels total), and three 0.25-inch thick hardened steel plates (24 panels total). Coatings were applied by vendors or by FMC Materials Engineering Laboratory following vendor supplied application specifications. Individually coated Q-panels were subjected to the tests described below and rated by the means specified to permit an evaluation of each coating in each individual test:

- Salt spray resistance per ASTM B117 using scored panels and 5% salt spray at 95° F. Coatings were judged by hours of continuous exposure until corrosion was detected.

- Humidity resistance per ASTM D2247 using scored panels and 100% humidity at 100° F. Coatings were judged by hours of continuous exposure until coating blisters or rust spots were detected.

- Flexibility per ASTM D1737 with a 1/4-inch diameter bar for 90° and 180° bends. Coatings were judged to have failed if coating cracked. Failed coatings were subsequently tested on a 1-inch diameter bar. The ratings was either "passed" or "failed".

- Adhesion per ASTM D3359, Method B, using a scoring tool to inscribe the coating with a crosshatch pattern. Adhesive tape was then applied to the squares and removed rapidly. A rating system of numbers was used with (5) for best adhesion and (0) for no adhesion.

- Abrasion resistance was measured with the Taber Abraser using CS17 wheels, 1,000 grams load, and operating for 100 cycles. Coatings were judged by milligrams of weight loss per 100 cycles.

- Immersion in diesel fuel at room temperature for seven days. Coatings were rated as either "unaffected" or "affected" with changes detailed.

- Impact resistance of candidate coatings was evaluated through the use of a chisel-edged, hardened tool. Candidate coatings were applied to hardened steel plates. Hardened plates were used to simulate the resistance to denting provided by a torsion bar because any deformation of the metal subsurface could cause loss of coating adhesion. The tool simulated the edge of a mechanics tool or steel part that could accidentally drop on a vehicle installed torsion bar. Hardening of the tool prevented the impacting edge from defroming during use. This test was meant to provide a deliberately severe "worst case" impact condition. Figure 2 shows the method used to impact damage the coatings on test panels, plates, and torsion bars.

Standard Impact Test

The impact energy level used for initial laboratory investigation work and for the remainder of this program was established by conducting a series of drop tests on a hardened steel plate covered with tape and primer. Impact energy imparted by the chisel edge to the coating was varied from 1 to 15 in-lb by dropping the fixture weight from increasing heights. Each drop was performed three times on the plate to provide a larger data base. Plates then were subjected to a 24-hour salt spray test to corrode the steel substrate at impact areas where both tape and primer had been penetrated. A careful inspection of impact areas revealed that all energy levels above 3 in-lb penetrated to the steel. Based on this finding, an energy level of 10 in-lb was selected as the "standard impact test" for the remainder of this program so that a qualifying coating would have a minimum of three times the impact energy resistance of the present system.

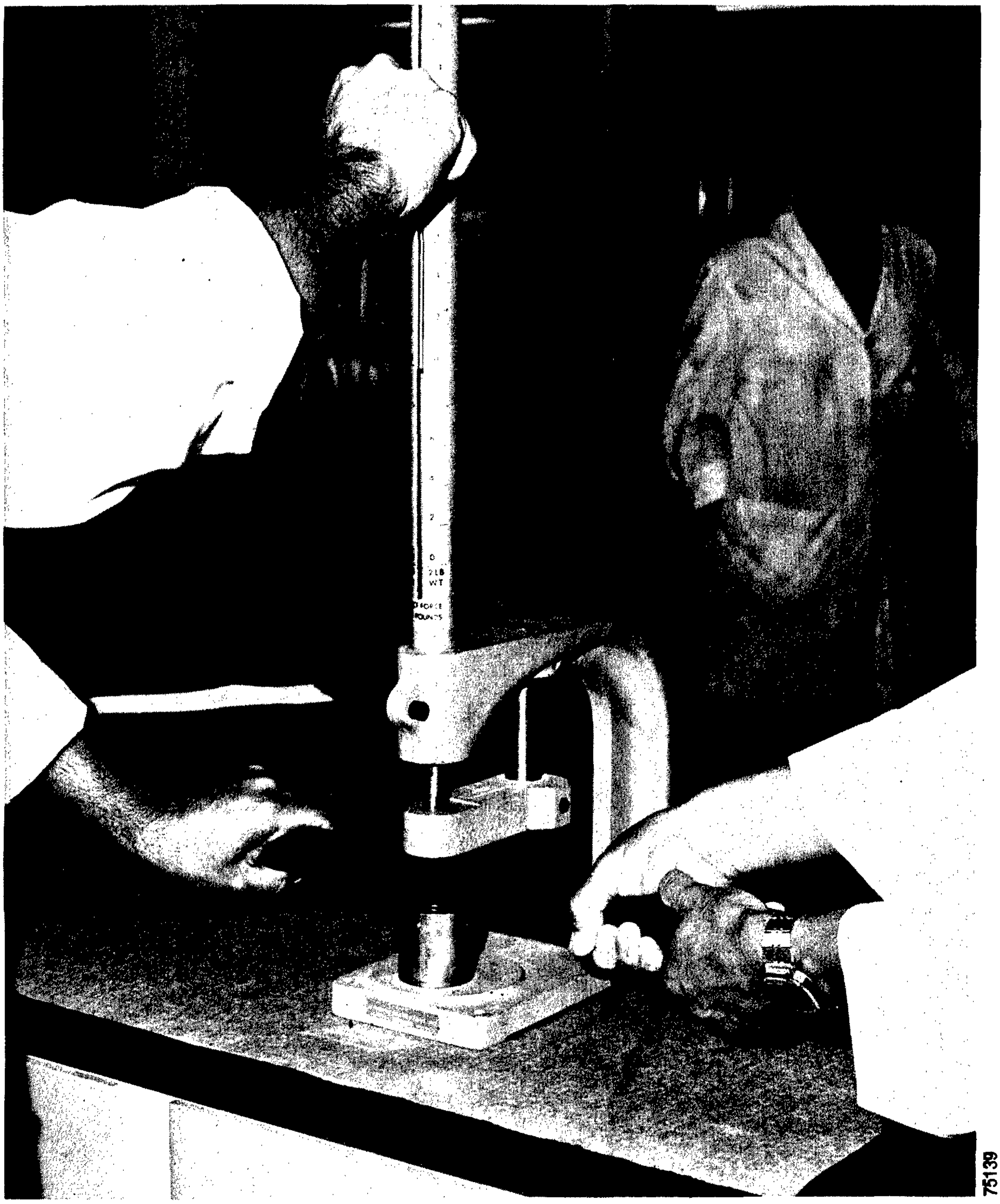

Figure 2. Method Used to Impact Damage the Coatings on Test Panels and Torsion Bars

Determination of Cost Effectiveness

Candidate coatings were ranked by assigning comparative values based on initial laboratory investigation tests. Values ranged from zero (lowest rating) to ten (highest rating) and it was assumed that each of the seven tests performed was of equal importance. Ranking based on total points is shown in Figure 3 with the effectiveness baseline coating (tape and primer) at the top for comparison.

Complete results of initial laboratory investigation tests are presented in Appendix A. Photographs of a representative group of Q-panel and plate test specimens are in Appendix B.

COATING	SALT SPRAY RESISTANCE	HUMIDITY RESISTANCE	FLEXIBILITY	ADHESION	ABRASION RESISTANCE	IMMERSION IN DIESEL FUEL	IMPACT RESISTANCE	TOTAL POINTS
TAPE & PRIMER (Effectiveness baseline)	10	10	10	10	6	0	2	48
ELASTUFF 701 POLYURETHANE	10	7	10	10	10	10	10	67
PLASTISOL	5	7	10	10	9	10	10	61
ELASTUFF 504 POLYURETHANE	10	5	10	10	4	9	10	58
IVADIZE	8	3	10	10	7	10	10	58
INJECTION MOLDED POLYURETHANE	5	7	10	10	4	10	10	56
CARBOZINC SP81	10	10	0	0	8	10	10	48
DACROMET 320	3	4	10	10	0	10	10	47
ALUMAZITE Z	2	2	10	10	5	10	0	39

Figure 3. Coating Effectiveness Ranking

On the basis of this analysis, testing of the four lowest ranked coatings was discontinued for reasons stated:

- INJECTION MOLDED POLYURETHANE - Coating of torsion bars would require a considerable amount of development effort that was beyond the scope of this project. The problem lies in maintaining uniform coating thickness with a long split mold when bars are permitted to have as much as 1/4-inch of full length curvature.

- CARBOZINC SP 81 - Failed flexibility and adhesion tests.

- DACROMET 320 - Coating was penetrated during abrasion test, exposing steel panel. Salt spray resistance was comparatively low. Curing temperature of 575° F is too high for this application. Reducing the cure temperature to the 350° F acceptable upper limit increases cure time to over an hour because of torsion bar mass.

- ALUMAZITE Z - Low salt spray and humidity resistance. Failed impact test.

For the next part of Phase I, to facilitate the selection of two coatings from the four remaining candidates, cost data was obtained from coating manufacturers and commercial coating vendors. Coating costs were based on a yearly quantity of 10,000 bars, and include tooling costs (unit costs for the tape and primer system were obtained from Machine Products Company, La Crosse, WI, and reflect current production costs). Figure 4 presents unit costs for coating M113A2 and M48/M60 torsion bars with tape and primer, and for the four most effective candidates. After an evaluation of both cost and effectiveness factors, Plastisol and Elastuff 701 were selected as the most promising candidates for application to torsion bars and continued investigation.

COATING	M113A2 (P/N 12268689)	M48/M60 (P/N 7359890)
Tape and Primer (cost baseline)	$ 4.25	$ 8.50
Plastisol	6.88	7.80
Elastuff 701	11.49	19.22
Elastuff 504	14.95	25.08
Ivadize	13.50	29.00

Figure 4. Costs for Coating Production Torsion Bars with Tape and Primer System and Most Cost Effective Candidates

Endurance Test Set-up

The objective of the last part of the Phase I effort was to prove that the more cost effective coating provides a significant improvement in impact and corrosion protection over the tape and primer system. To accomplish this task, a series of bench endurance tests were performed using 1/3 length torsion bars. Forty bars were procured from Machine Products Company, manufactured to the requirements of MIL-S-45387 with the exception that thirty bars were delivered without tape and primer to facilitate the application of candidate coatings.

Test bars were configured with M113-size splines and a 1.3-inch body diameter, providing a design stress balance which would assure fatigue failures in the body section, permitting evaluation of differences in corrosion resistance afforded to the body section by various coatings. Bars were tested in the fixture shown in Figure 5, powered by a hydraulic actuator. Continuous load control was employed to maintain a calculated outer fiber shear stress range of 8,000 to 160,000 psi in the body section. This range corresponds to the 6% to 114% of the

MIL-S-45387 torsion bar design stress (140,000 psi). Based on similar tests conducted recently, the increased stress level was selected to assure that endurance failures would occur in a reasonable length of time. All test bars were preset by the manufacturer per standard practice.

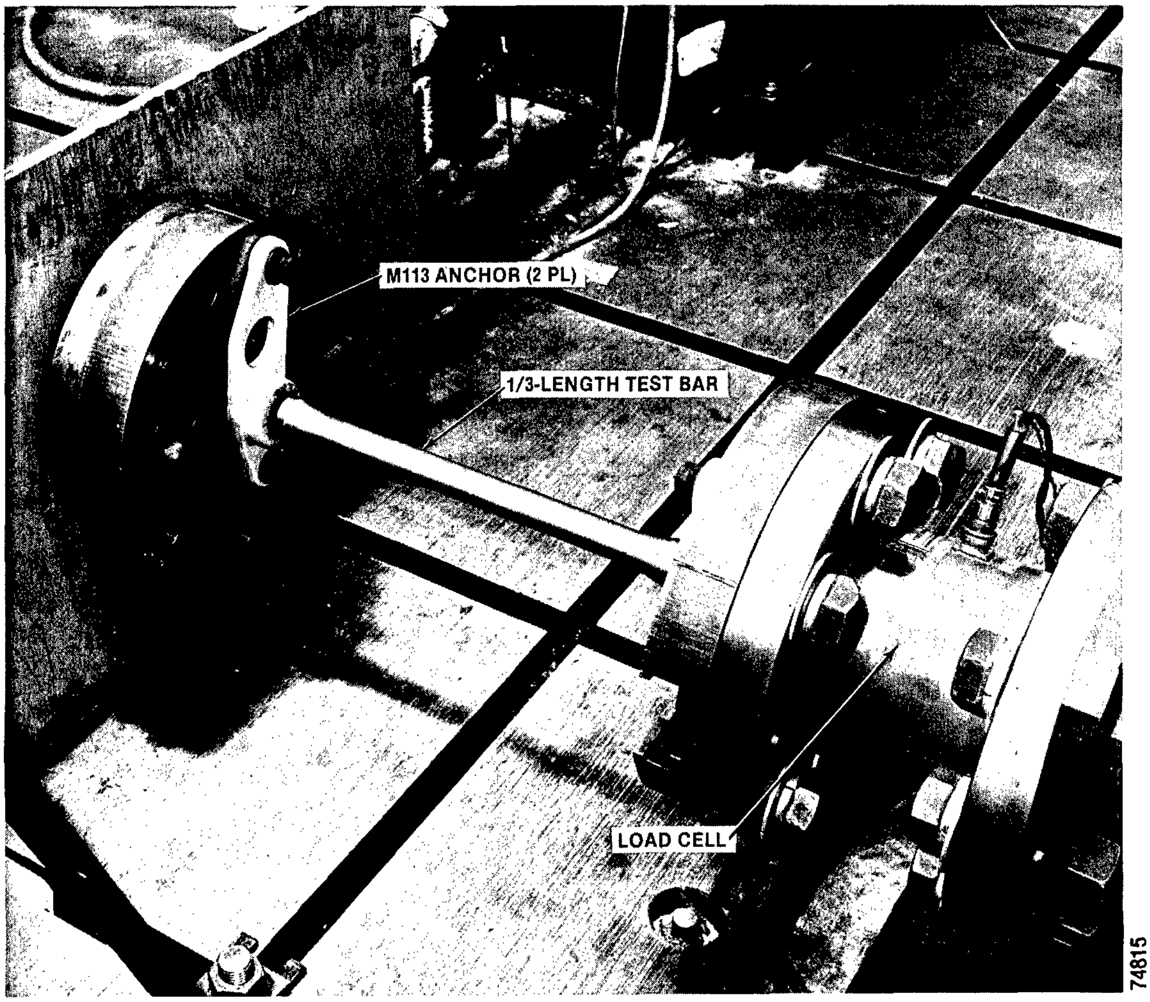

Figure 5. Torsion Bar Endurance Test Fixture Shown with Scatter Shield Removed

The first attempt at generating a corrosion/fatigue failure in the torsion bar body was concluded after four days of test. The method used, shown in Appendix C, involved circulating a brine solution around the bar body section while endurance testing the bar at a low cyclic rate. The coating had been damaged by the standard impact test method prior to bar installation. Although brine temperature was raised and bleed air added to increase the rate of corrosive attack, the bar did not fail and this test was discontinued. It was concluded that an endurance test requiring more than four days was not consistent with the time constraints of this program.

Standard Damage/Corrosion Method

The successful method used to produce coating damage and induce corrosion in test bars for the remainder of this program is shown in Appendix D Sketch 070180. In this procedure, coating damage was imposed by the standard impact test method described earlier. After application of a protective mask to the lower spline, the bar was immersed for 72 hours in a Copper Accelerated Salt Spray* (CASS) solution. Upon removal from immersion, the spline mask was removed and the bar thoroughly rinsed with water to terminate corrosive attack before endurance testing until the body (or spline) failed.

One-Third Length Bar Test

Four groups of one-third length test bars were endurance tested. Characteristics of each group and their significance to the program are described below:

Group I - Uncoated (bare), undamaged bars with no CASS immersion were tested to establish a "best case" endurance life baseline for MIL-S-45387 torsion bars.

Group II - Tape and primer coated body per MIL-S-45387 and subjected to the standard damage/corrosion method. These bars would provide data on the endurance of bars that had been subjected to a corrosive attack.

*ASTM B368 test modified by substituting liquid immersion for fog; and exposure at 70° F rather than 120° F.

Group III - Plastisol coated body. Subject to the standard damage/ corrosion method. To prove successful as the Improved Coating System, endurance had to significantly exceed that of Group II. In the ideal case, life would equal that of Group I.

Group IV - Elastuff 701 coated body. Subjected to standard damage/ corrosion method. Same success criterion as for Group III.

Individual results for each test are presented in Appendix E with bars arranged by groups. It should be noted that a number of undesirable spline failures occurred. Metallurgical analysis of fracture sites indicated that failures were caused by either surface discontinuities at the spline root, or nonuniform shot peening. After identification of this problem early in the program, special attention was given to fixture alinement to reduce the possibility of bending stresses in the splines.

Statistical Analysis of Bar Test

Endurance analysis was performed using a computer program employing Weibull Maximum Likelihood Estimator techniques. This MLE* class was chosen because of the mathematical precision obtained and because results are impervious to sample censoring. Five bars (numbers 1, 2, 3, 8, and 10) were deleted from life analysis because they were used to develop test procedures (ref. Appendix E, notes 1-5). Bar number 40 was not tested. A summary of estimated parameters for the thirty-four bars tested, according to the Weibull Law, is presented in Figure 5. A comparison of censored and uncensored life analysis is presented for each group that experienced spline failures.

* Maximum Likelihood Estimate

The Weibull distribution has the functional form:

$$f(x) = \frac{\beta x^{\beta-1}}{\eta^{\beta}} \exp - (x/\eta)^{\beta}$$

Where, x = life value,

β = shape parameter,

η = scale parameter

The shape parameter determines the relative shape of the probability density function. When considering shape parameter alone, increased magnitude shifts the density peak away from early failure in the direction of extended life. The scale parameter represents an adjustment of the scale of life values according to the relative length of lives. Thus, a higher scale parameter also corresponds to extended life. Mode cycles is the positon of the peak of the density function curve and estimates the most frequently occurring life.

ENDURANCE TEST GROUP	& COATING	COATING DAMAGE/ CORROSION	SAMPLE SIZE (n)	NUMBER OF SAMPLES CENSORED	MLE* SHAPE (β)	MLE* SCALE (η)	MODE (CYCLES)	ARITHMETIC AVERAGE (CYCLES)
I-A	None	None	6	0	3.574	120,869	110,263	108,780
II-A	Tape/Primer	Std. Method	8	0	1.824	66,591	43,074	58,650
II-B	Tape/Primer	Std. Method	8	1(spline)	1.7298	70,906	43,054	58,650
III-A	Plastisol	Std. Method	12	0	2.3585	112,271	88,856	99,370
III-B	Plastisol	Std. Method	12	9(spline)	2.6352	194,978	162,682	99,370
IV-A	Elastuff 701	Std. Method	9	0	1.9815	96,092	67,408	74,910
IV-B	Elastuff 701	Std. Method	9	3(spline)	1.7565	117,997	73,049	74,910

*MLE — Maximum Likelihood Estimate

Figure 6. Summary of Estimated Parameters for Accelerated Test of One-Third Length Torsion Bar

Referring to Figure 6, it is apparent that Group III-B Plastisol coating system with censored samples presents the highest shape parameter (2.6352) and the highest mode cycles (162,682) of the three torsion bar coating systems tested in this program. A comparison of the arithmetical averages reveals that Plastisol offers 41% more life than the tape and primer system and 24% more life than Elastuff 701. It can be observed that Plastisol protected bars provide a protection closest to the "best case" Group I-A baseline. Shape parameters for all four torsion bar groups fell within the shape class termed "random cyclic" indicating a somewhat random but generally early life failure.

As Phase I was completed, it was determined that on the basis of application costs, results of the initial laboratory investigation, and protection level demonstrated by endurance testing one-third length torsion bars, Plastisol was the most cost-effective coating tested. It was, therefore, selected for Phase II performance verification testing.

PHASE II

Production Bar Test

The objective of Phase II was to verify that the Improved Coating System (Plastisol) determined to be most cost-effective in Phase I, provides an improvement in corrosion protection to production torsion bars, when compared to the current tape and primer system. This task was accomplished through performance of two endurance tests employing a total of sixteen production M113A2 torsion bars purchased from Machine Products Company. Eight of these P/N 12268689 bars were purchased to the requirements of MIL-S-45387, including the standard tape/primer coating. The remaining eight bars were purchased bare, to facilitate the application of Plastisol.

The M113A2 torsion bar is designed for a 160,000 psi stress level. With this in mind, an outer fiber shear stress range of 9,000 to 180,000 psi in the body section was selected for endurance testing to assure that failures would occur in a reasonable length of time. This range corresponds to 6% to 113% of design stress. Sinusoidal motion with continuous load control was employed during each test, using the test fixture shown in Figure 5. A modification was made to mount M113 torsion bar anchors on pins to permit self-alinement, thereby removing the possibility of induced bending stresses which may have contributed to the Phase I spline failures.

All bars were subjected to the standard damage/corrosion method (Appendix D) prior to endurance testing. Tape and primer coated bars were tested first, to establish an endurance life for bars that had sustained a corrosive attack at the damage sites. Plastisol coated bars, effectively protected from corrosive attack, were subsequently life tested and results of the two groups statistically compared.

TORSION BAR NUMBER	BODY COATING	ENDURANCE LIFE	LOCATION OF FAILURE	DAMAGE/CORROSION METHOD EMPLOYED
40	Tape & Primer	37,990	Body @ DS***	Standard**
41	Tape & Primer	42,720	Body @ DS	Standard
42	Tape & Primer	17,800	Body @ DS	Standard
43	Tape & Primer	25,160	Body @ DS	Standard
44	Tape & Primer	21,730	Body @ DS	Standard
45*	Tape & Primer	2,850	N/A, Note 1	Standard
46	Tape & Primer	11,260	Body @ DS	Standard
47	Tape & Primer	4,190	Body @ DS	Standard

Average Life = 22,980 (Deleted bar number 45)
Std. Deviation ($\hat{\sigma}$) = 13,775

48	Plastisol	46,850	Spline	Standard**
49	Plastisol	22,190	Spline	Standard
50	Plastisol	30,710	Spline	Standard
51	Plastisol	50,250	Spline	Standard
52	Plastisol	42,540	Spline	Standard
53*	Plastisol	11,400	Body, Note 2	Standard
54	Plastisol	46,810	Spline	Standard
55*	Plastisol	5,610	Body, Note 2	Standard

Average Life = 39,890 (Deleted bar number 53 and 55)
Std. Deviation ($\hat{\sigma}$) = 11,029

*Deleted from Data Analysis.
**Standard Damage/Corrosion Method is shown in Appendix D.
***DS indicates Damage Site.

NOTE 1 - Bar did not fail. Test was terminated when test fixture failed.

NOTE 2 - Failure attributed to surface defect.

Figure 7. Endurance Test Results for M113A2 Production Torsion Bar, P/N 12268689

Seven bars with the tape and primer system were endurance tested to failure. The eighth bar (number 45) was damaged when a failure of the test fixture occurred, causing it to be deleted from statistical analysis. Eight Plastisol coated bars were tested to failure. Two of these bars (numbers 53 and 55) suffered early failure and also were deleted. Metallurgical analysis revealed that surface defects associated with improper handling during manufacture was the cause of failure. Individual results for each bar test are presented in Figure 7 with bars arranged by groups.

Statistical Analysis of Bar Test

Endurance analysis was performed using a computer program, again employing Weibull Maximum Likelihood Estimator techniques. A summary of estimated parameters for the thirteen Phase II bars is presented in Figure 8.

ENDURANCE TEST GROUP & COATING	COATING DAMAGE/ CORROSION	SAMPLE SIZE (n)	NUMBER OF SAMPLES CENSORED	MLE* SHAPE (β)	MLE* SCALE (η)	MODE (CYCLES)	ARITHMETIC AVERAGE (CYCLES)
Tape and Primer	Std. Method	7	0	1.8532	25,891	17,036	22,980
Plastisol	Std. Method	6	0	5.1587	43,657	41,881	39,890

*MLE — Maximum Likelihood Estimate

Figure 8. Summary of Estimated Parameters for Accelerated Test of M113A2 Torsion Bar

Note that six Plastisol protected bars experienced spline failures. This is an acceptable failure mode for a production torsion bar protected from body corrosion because the bar was designed to develop similar stress levels in both body and splines. All spline fracture sites were reviewed to verify that failures had resulted from fatigue.

As discussed earlier, shape parameter determines the relative shape of the density function. The low shape parameter (1.8532) exhibited by tape/primer coated bars skews the failure distribution toward early life failure. Figure 9 is a computer generated representation of the probability density function (PDF) for this case. The mode parameter noted on Figure 9 is the most frequently occurring life for tape and primer coated bars.

Figure 10 presents a similar representation of the PDF associated with the Plastisol coated bars. Comparison of curves in Figures 9 and 10 reveals a distinct difference in failure form. Tape and primer coated bars appear to have a short life (due to corrosion) as indicated by the low shape parameter (1.8532), whereas Plastisol protected bars with a much higher shape parameter (5.1587) have a longer life and tend to fail from fatigue. Note also that the mode parameter for Plastisol (41,881 cycles) is shifted away from the early failure that is exhibited by the tape/primer system (17,036 cycles). This shift represents a 146% increase in the most commonly expected life for Plastisol protected torsion bars. Further proof of increased life is provided by the fact that all Plastisol protected bars failed in the splines, indicating that corrosion did not penetrate the Plastisol, whereas all tape and primer coated bars failed at body damage/ corrosion sites.

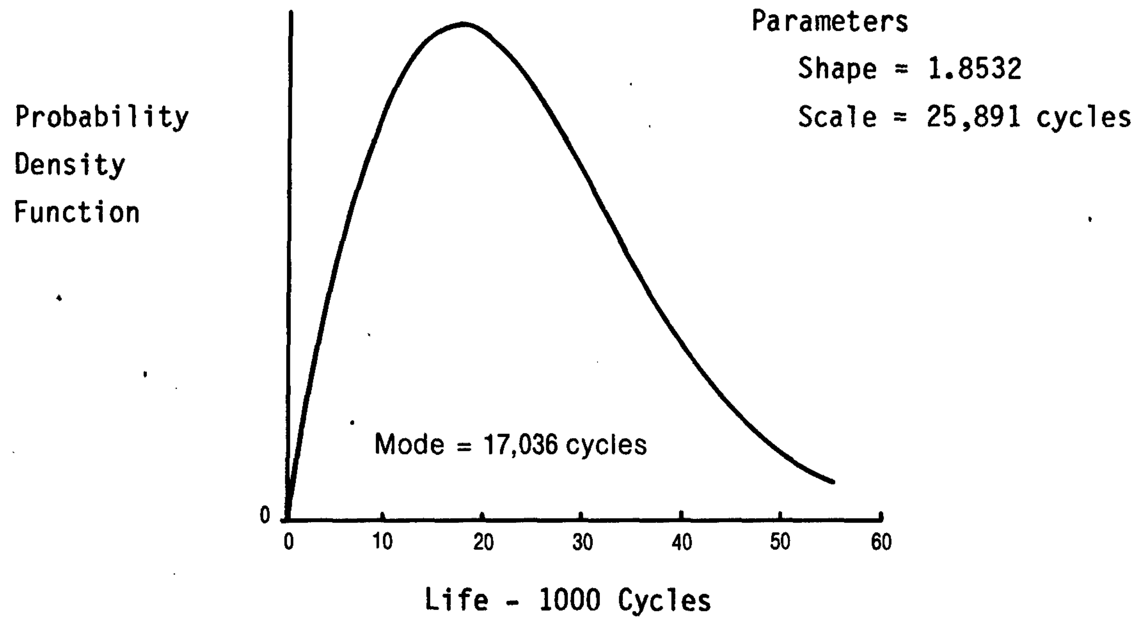

Figure 9. Probability Density Function Curve for Tape and Primer Coated Production M113A2 Torsion Bar*

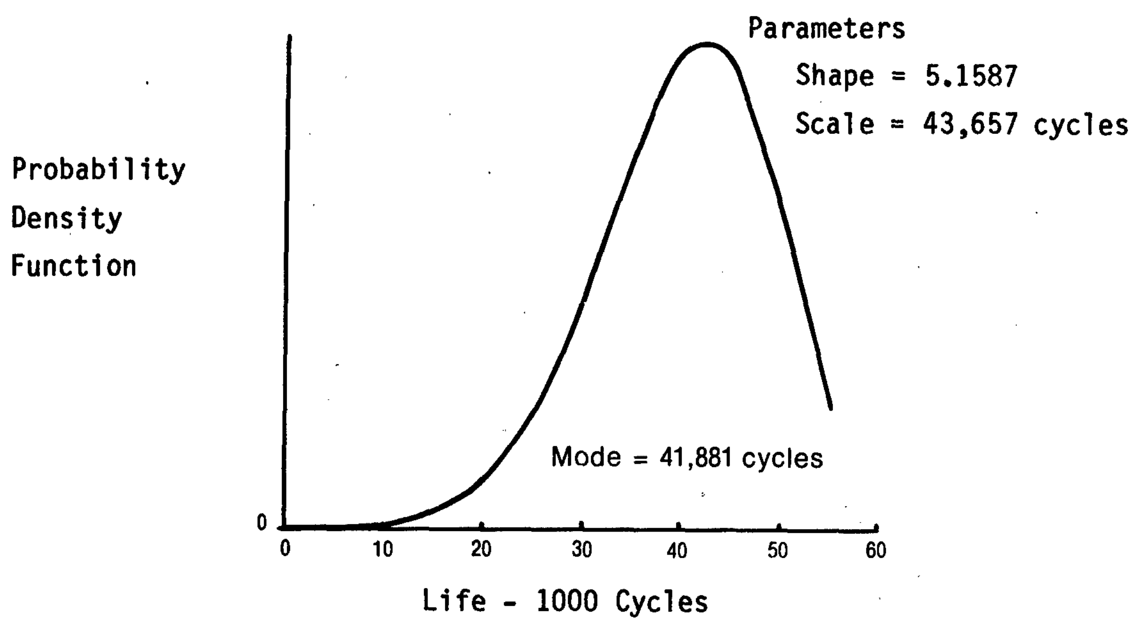

Figure 10. Probability Density Function Curve for Plastisol Coated Production M113A2 Torsion Bar*

*Accelerated test @ 113% of design stress

Verification of Methodology

Figure 11 shows three M48/M60 P/N 7359890 torsion bars that were coated with Plastisol to verify that technology required for application on the largest production torsion bar in the military system is available. The coating was applied by Production Engineering Company, San Rafael, CA, using the vertical dipping process. These bars have been shipped to the TACOM Track and Suspension Lab for evaluation.

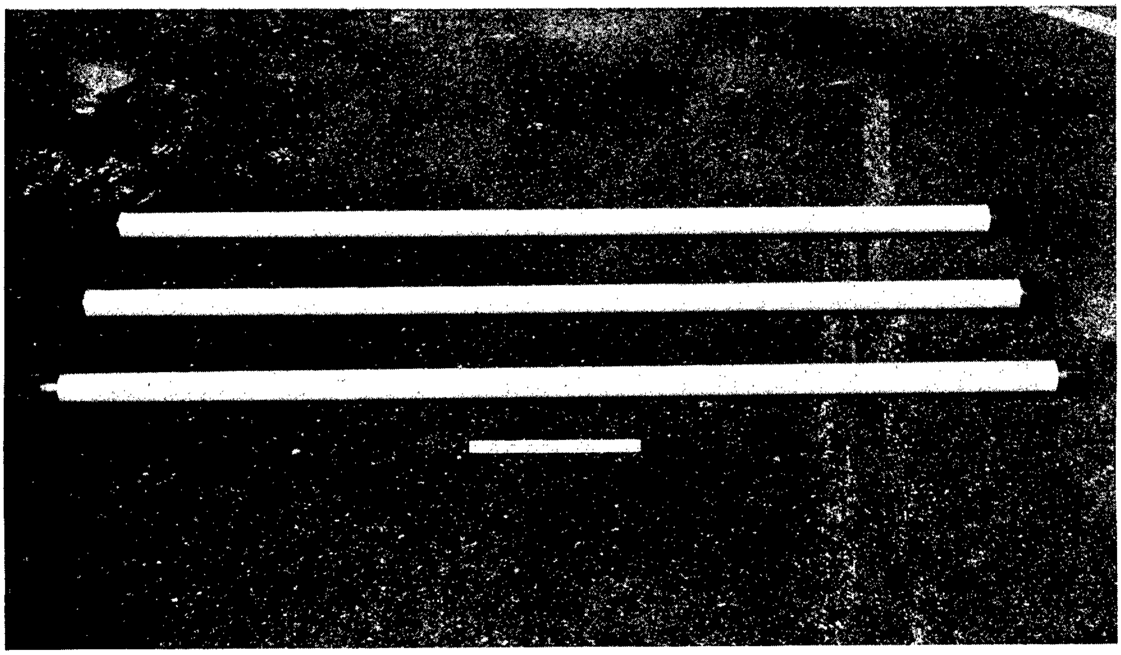

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Figure 11. Improved Coating System (Plastisol) Applied to M48/M60 Tank Torsion Bars

CONCLUSIONS

It has been demonstrated that Plastisol applied by the vertical dip method is the most cost effective coating of the eight candidate coatings evaluated during this program. Based on the current M113A2 torsion bar cost (300M material with tape and primer coating) of approximately $170, the Plastisol coating will increase bar cost by less than 2% while increasing bar life by 146%. Even greater savings can be achieved for the M48/M60 bar where the Plastisol coating costs less than tape and primer.

RECOMMENDATIONS

It is recommended that the Requirements Section of specification MIL-S-45387, Torsion Bar Spring Suspension, be revised to delete the use of tape and primer as a torsion bar coating system, and that Plastisol, Type I or II, Class 2, Specification MIL-P-20689, be applied in its place, per the method outlined in Appendix F.

APPENDIX A

RESULTS OF INITIAL LABORATORY INVESTIGATION TESTS

SALT SPRAY RESISTANCE TEST RESULTS

ASTM B117 method using scored panels and 5% salt spray at 95° F.

	COATING	DRY FILM THICKNESS-MILS	TOTAL EXPOSURE TIME WHEN CORROSION DETECTED-HOURS
Most Protection	Carbozinc SP81	3.1	1632*
	Elastuff 504 Polyurethane	15.0	1632*
	Elastuff 701 Polyurethane	20.0	1632*
	Tape & Primer	10.0	1632*
	Ivadize	1.0	1632
	Plastisol	50.0	864
	Injection Molded Polyurethane	50.0	864
	Dacromet 320	0.1	648
Least Protection	Alumazite Z	0.6	336

*No failure occured. Test was terminated.

APPENDIX A (cont'd)

HUMIDITY RESISTANCE TEST RESULTS

ASTM D2247 method using scored panels and 100% humidity at 100° F.

	COATING	DRY FILM THICKNESS-MILS	TOTAL EXPOSURE TIME WHEN CORROSION DETECTED-HOURS
Most Protection	Carbozinc SP81	3.1	2016*
	Tape & Primer	10.0	2016*
	Elastuff 701 Polyurethane	20.0	1224*
	Injection Molded Polyurethane	50.0	1224*
	Plastisol	50.0	1224*
	Elastuff 504	15.0	1032 Rust spots detected
	Dacromet 320	0.1	936 Rust spots detected
	Ivadize	1.0	552 Rust spots detected
Least Protection	Alumazite Z	0.6	336 Rust spots detected

*No failure occured. Test was terminated.

FLEXIBILITY TEST RESULTS

ASTM D1737 method with 1/4-inch diameter bar for both 90° and 180° bends. Coatings that exhibited cracks were subsequently tested on a 1-inch diameter bar. "Passed" indicates no cracking occurred.

COATING	1/4-INCH DIAMETER BAR 90° BEND	1/4-INCH DIAMETER BAR 180° BEND	1-INCH DIAMETER BAR 90° BEND
Alumazite Z	Passed	Passed	NA
Dacromet 320	Passed	Passed	NA
Elastuff 504 Polyurethane	Passed	Passed	NA
Elastuff 701 Polyurethane	Passed	Passed	NA
Ivadize	Passed	Passed	NA
Plastisol	Passed	Passed	NA
Injection Molded Polyurethane	Passed	Passed	NA
Tape & Primer	Passed	Passed	NA
Carbozinc SP81	Failed	Failed	Failed

ADHESION TEST RESULTS

ASTM D3359 Method B using a scoring tool to inscribe the coating with a crosshatch pattern. Tape was then applied to the square grid and removed rapidly.

COATING	ADHESION RATING
Alumazite Z	Excellent adhesion
Dacromet 320	Excellent adhesion
Elastuff 504 Polyurethane	Excellent adhesion
Elastuff 701 Polyurethane	Excellent adhesion
Ivadize	Excellent adhesion
Plastisol	Excellent adhesion
Injection Molded Polyurethane	Excellent adhesion
Tape & Primer	Excellent adhesion
Carbozinc SP81	No adhesion

ABRASION RESISTANCE TEST RESULTS

Taber Abraser test fixture with CS17 wheels, 100 grams load, operated for 1,000 cycles or until coating was penetrated.

	COATING	DRY FILM THICKNESS-MILS	WEIGHT LOSS MILLIGRAMS/100 CYCLES
Most Protection	Elastuff 701 Polyurethane	10.0	0.06
	Plastisol	65.0	2.27
	Carbozinc SP81	3.0	5.36
	Ivadize	1.1	7.50
	Tape & Primer	10.0	30.00
	Alumazite Z	0.5	102.30
Most Weight Lost	Elastuff 504 Polyurethane	15.0	985.00
	Injection Molded Polyurethane	59.0	See Note 1
	Dacromet 320	0.2	7.50*

NOTE 1: Unable to obtain accurate readings. Panel gained weight because abrasive particles adhered to coating.

*Penetrated coating, exposing steel panel

APPENDIX A (cont'd)

IMMERSION IN DIESEL FUEL TEST RESULTS

Immersion in diesed fuel at room temperature for seven days.

COATING	CONDITION AFTER 7 DAYS
Alumazite Z	Unaffected
Carbozinc SP81	Unaffected
Dacromet 320	Unaffected
Elastuff 701 Polyurethane	Unaffected
Ivadize	Unaffected
Plastisol	Unaffected
Injection Molded Polyurethane	Unaffected
Elastuff 504 Polyurethane	Affected Color faded, no other effect
Tape & Primer	Affected Tape peeled from edges. Swelling and softening of adhesive observed.

APPENDIX A (cont'd)

IMPACT RESISTANCE TEST RESULTS

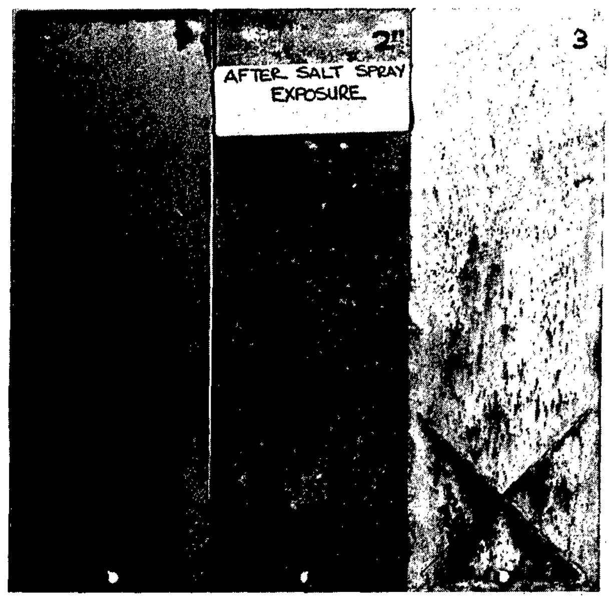
Method employed a chisel-edged, hardened tool and 1/4-inch thick, hardened and coated plates. A series of impact tests at energy levels indicated below were performed on each sample, followed by a 24-hour salt spray exposure to induce corrosion where coating had been penetrated.

	IMPACT ENERGY INCH-POUNDS					
COATING	1	3	5	8	10	15
Carbozinc SP81	X	X	X	X	X	X
Dacromet 320	X	X	X	X	X	X
Elastuff 504 Polyurethane	X	X	X	X	X	X
Elastuff 701 Polyurethane	X	X	X	X	X	X
Ivadize	X	X	X	X	X	X
Plastisol	X	X	X	X	X	X
Injection Molded Polyurethane	X	X	X	X	X	X
Tape & Primer	X	X	Failed	Failed	Failed	Failed
Alumazite Z	Failed	Failed	Failed	Failed	Failed	Failed

X = Coating not penetrated

APPENDIX B

SELECTED PHOTOGRAPHS OF COATED Q-PANELS AND PLATES TESTED DURING THE INITIAL LABORATORY INVESTIGATION



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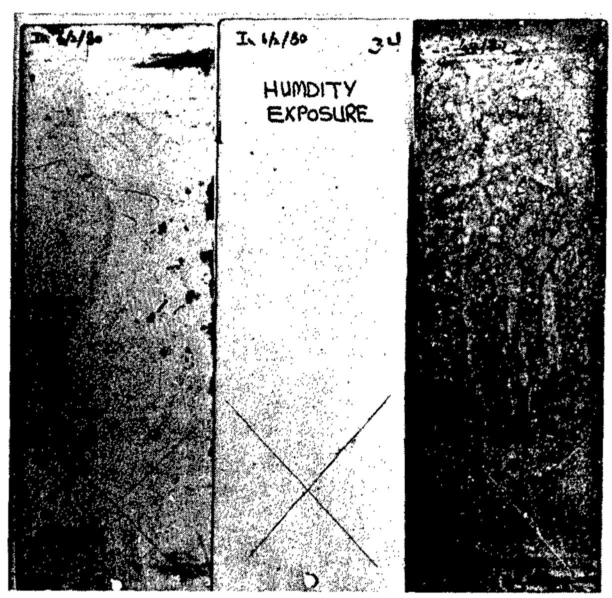
Alumazite Z   Dacromet 320   Ivadize

<u>SALT SPRAY RESISTANCE</u>   Alumazite Z coating exhibited least protection (336 hours) of all coatings tested.



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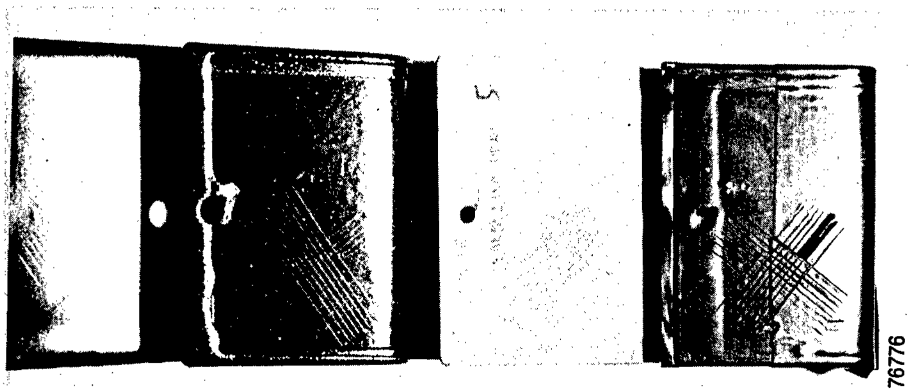
Alumazite Z   Ivadize   Dacromet 320

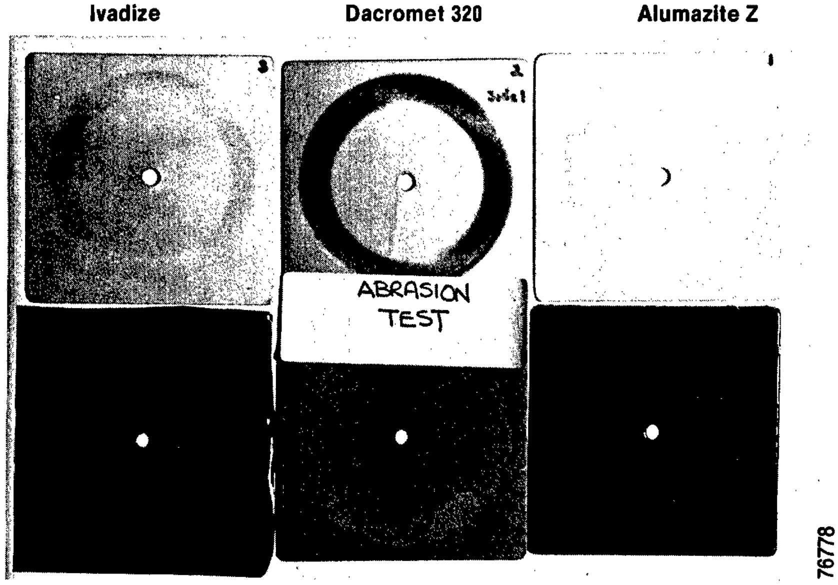
<u>HUMIDITY RESISTANCE</u>   Alumazite Z coating exhibited least protection (336 hours) of all coatings tested.



Elastuff 701 Elastuff 504 Carbozinc SP81 Tape & Primer

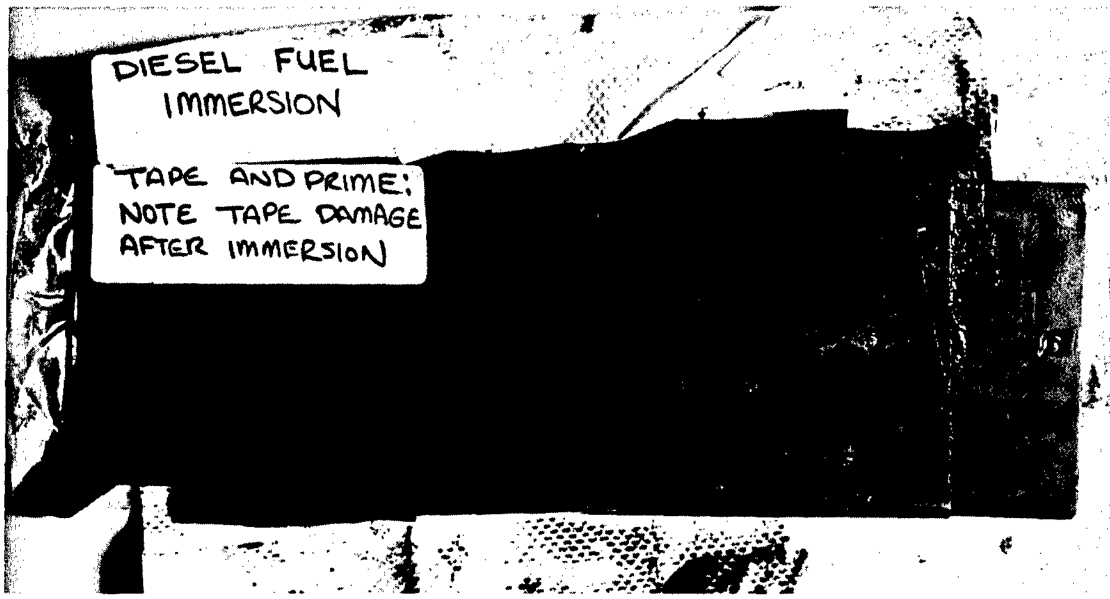
FLEXIBILITY & ADHESION Carbozinc SP81 coating failed both tests and was the only failure of all coatings tested.

Ivadize Dacromet 320 Alumazite Z



Tape & Primer Carbozinc SP81 Elastuff 504

ABRASION RESISTANCE Dacromet 320 coating was penetrated, exposing steel panel.



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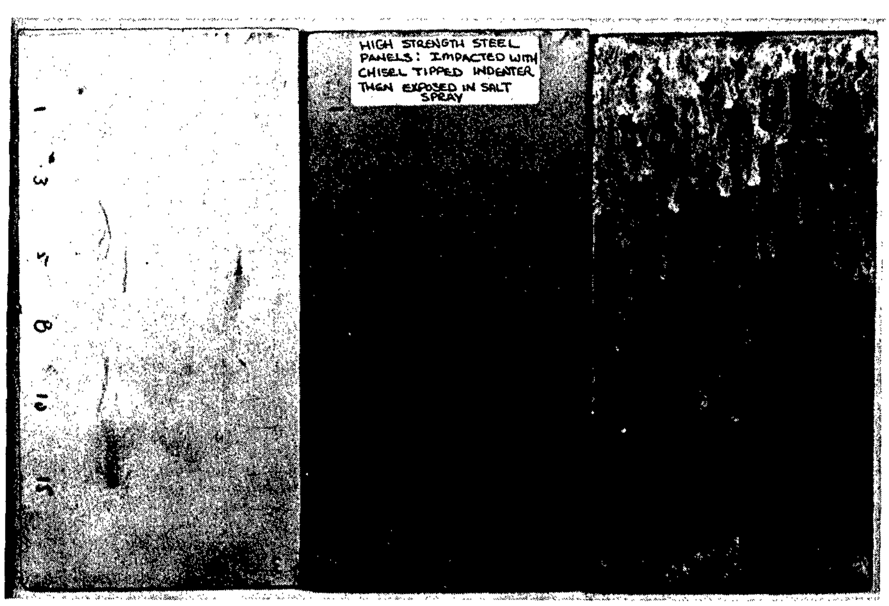
IMMERSION IN DIESEL FUEL Tape adhesive swelled and softened. Tape slid away from primed panel.



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Ivadize **Alumazite Z** **Dacromet 320**

IMPACT RESISTANCE/SALT SPRAY CORROSION Numbers on hardened plates indicate impact energy level of chisel-edged tool. Three impacts were made on each plate at each energy level.

APPENDIX C

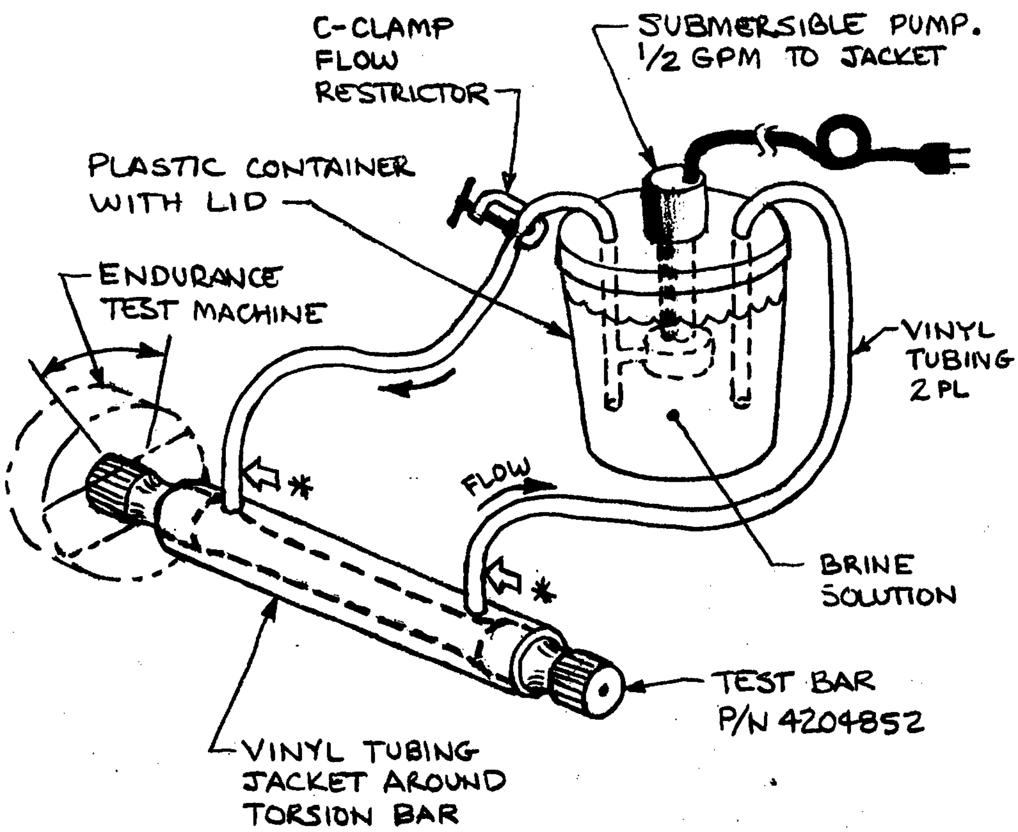
INITIAL METHOD USED TO GENERATE CORROSION/FATIGUE
IN ONE-THIRD LENGTH TEST BARS

6/8/80
Austin

SKETCH 060880

P/A 279

ARRANGEMENT for CORROSION/FATIGUE TEST
of 1/3 LENGTH P/N 4204852 TEST BARS

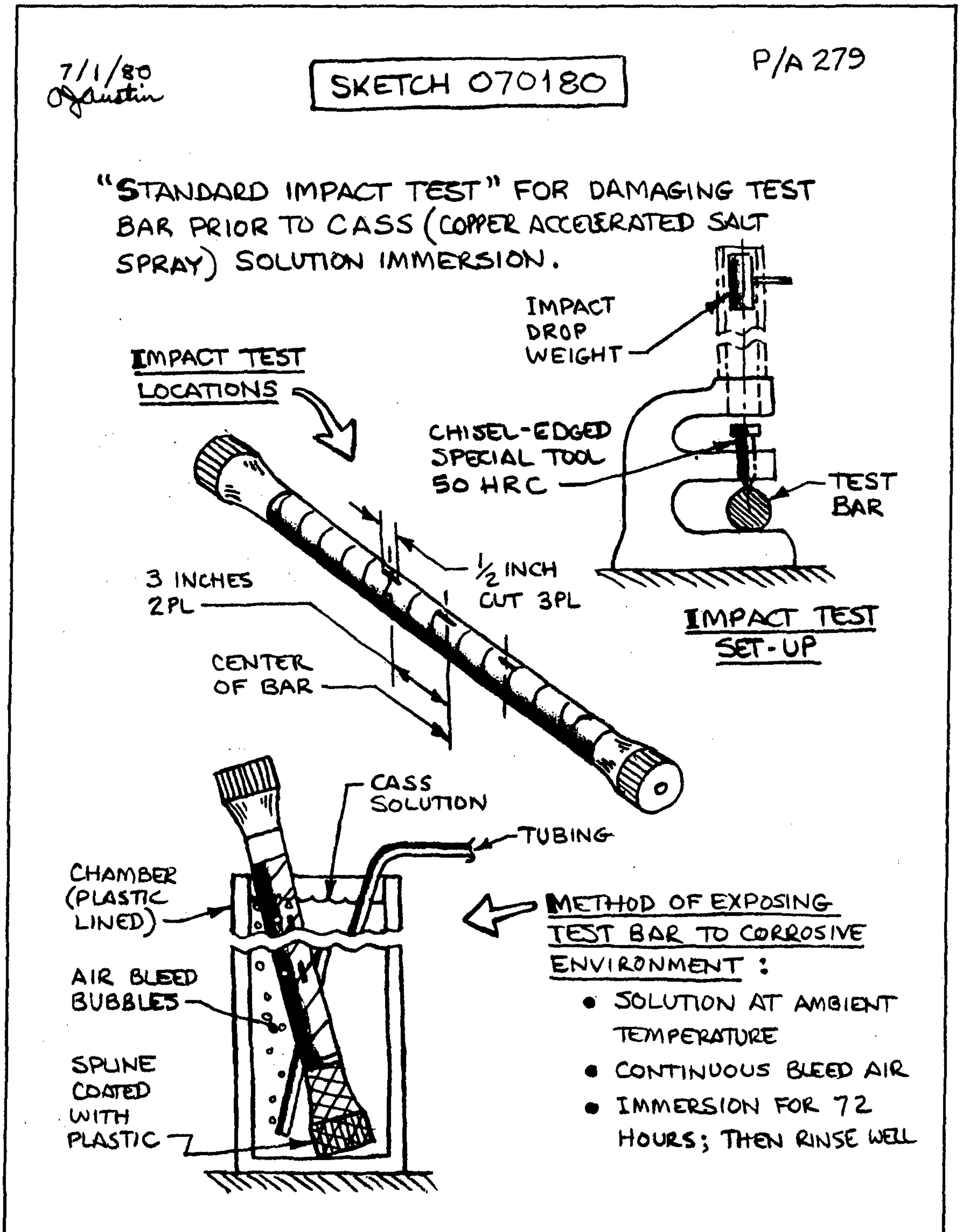


NOTE: BRINE SOLUTION MAY HAVE TO BE COOLED TO MAINTAIN A STABLE TEMPERATURE (±2°F)

* USE PINCH-OFFS AT THESE POINTS WHEN CHANGING TEST BAR/JACKET ASSY

APPENDIX D

STANDARD METHOD FOR PRODUCING DAMAGE AND INDUCING CORROSION IN ONE-THIRD LENGTH TEST BARS



APPENDIX E

ENDURANCE TEST RESULTS FOR ONE-THIRD
LENGTH TORSION BAR P/N 4204852

TORSION BAR NUMBER	BODY COATING	ENDURANCE LIFE	LOCATION OF FAILURE	DAMAGE/CORROSION METHOD EMPLOYED
Group I				
1*	Bare	38,000	Body	None, Note 1
2*	Bare	76,000	Spline	None, Note 2
3*	Bare	111,000	Spline	None, Note 2
4	Bare	114,000	Body	None
5	Bare	94,000	Body	None
6	Bare	107,000	Body	None
7	Bare	124,000	Body	None
28	Elastuff 701	164,340	Body	None
35	Bare	49,350	Body	None

Average Life = 108,780 (Deleted bar number 1,2, & 3)
Std. Deviation ($\hat{\sigma}$) = 37,680

TORSION BAR NUMBER	BODY COATING	ENDURANCE LIFE	LOCATION OF FAILURE	DAMAGE/CORROSION METHOD EMPLOYED
Group II				
8*	Tape & Primer	154,000	N/A	Note 3
9	Tape & Primer	44,925	Body	Standard**
10*	Tape & Primer	14,396	Body	Note 4
11	Tape & Primer	33,974	Body	Note 5
12	Tape & Primer	75,581	Spline	Standard
13	Tape & Primer	142,008	Body	Standard
14	Tape & Primer	64,323	Body	Standard
15	Tape & Primer	25,190	Body	Standard
16	Tape & Primer	33,740	Body	Standard
36	Tape & Primer	49,430	Body	Standard

Average Life = 58,646
Std. Deviation ($\hat{\sigma}$) = 37,600

Footnotes on page E-2

APPENDIX E (cont'd)

TORSION BAR NUMBER	BODY COATING	ENDURANCE LIFE	LOCATION OF FAILURE	DAMAGE/CORROSION METHOD EMPLOYED
Group III				
17	Plastisol	93,110	Spline	Standard**
18	Plastisol	224,870	Spline	Standard
19	Plastisol	122,180	Body	Standard
20	Plastisol	90,700	Body	Standard
21	Plastisol	115,340	Spline	Standard
22	Plastisol	71,530	Spline	Standard
23	Plastisol	43,740	Spline	Standard
24	Plastisol	52,410	Spline	Standard
29	Plastisol	107,010	Spline	Standard
37	Plastisol	92,740	Body	Standard
38	Plastisol	87,450	Spline	Standard
39	Plastisol	91,380	Spline	Standard

Average Life = 99,370
Std. Deviation ($\hat{\sigma}$) = 45,749

TORSION BAR NUMBER	BODY COATING	ENDURANCE LIFE	LOCATION OF FAILURE	DAMAGE/CORROSION METHOD EMPLOYED
Group IV				
25	Elastuff 701	22,620	Body	Standard**
26	Elastuff 701	39,860	Body	Standard
27	Elastuff 701	64,760	Body	Standard
30	Elastuff 701	91,390	Spline	Standard
31	Elastuff 701	53,440	Body	Standard
32	Elastuff 701	110,210	Spline	Standard
33	Elastuff 701	68,270	Spline	Standard
34	Elastuff 701	148,740	Body	Standard

Average Life = 74,910
Std. Deviation ($\hat{\sigma}$) = 40,601

*Deleted from data analysis.
**Standard damage/corrosion method is shown in Appendix D.

NOTE 1 - Tested between 0 and 160,000 psi shear stress.
NOTE 2 - Tested between 7,500 and 150,000 psi shear stress.
NOTE 3 - Standard damage method used. Brine solution and jacket per Appendix C. Bar did not fail.
NOTE 4 - Immersed in CASS for 168 hours.
NOTE 5 - Immersed in CASS for 88 hours.

APPENDIX F

SPECIFICATION FOR APPLICATION OF PLASTISOL TO HIGH STRENGTH TORSION BAR SPRINGS

PROTECTIVE COATING

1. Cleaning

   Prior to application of any coating, the torsion bar shall be cleaned in accordance with Method II of Spec. TT-C-490.

2. Coating

   Coat the body of the torsion bar with primer and Plastisol to Type I or II, Class 2, Specification MIL-P-20689. Coating thickness shall be 0.06 $\pm$ 0.03 inches. Color shall be black.

3. Process Controls

   - Processing temperature shall not exceed 350° F.
   - The threaded hole in the end of the torsion bar shall be kept clean.
   - If the surplus ends of the Plastisol coating are to be trimmed from the body of the bar, the underlying metal shall not be damaged.

4. Quality Assurance Provisions

   Adhesion shall be checked per para. 4.3.5.1 of MIL-P-20689 except that:

   - The test shall be carried out on the torsion bar instead of on a panel.
   - The torsion bar need not be subjected to water immersion.

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