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R-TR-77014

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ENVIRONMENTAL EXPOSURE AND ACCELERATED TESTING OF RUBBER-TO-METAL VULCANIZED BONDED ASSEMBLIES

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AUGUST 1975

TECHNICAL REPORT

RESEARCH DIRECTORATE

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GENERAL THOMAS J. RODMAN LABORATORY
ROCK ISLAND ARSENAL
ROCK ISLAND, ILLINOIS 61201

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 RIA R-TR-77-014	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 ENVIRONMENTAL EXPOSURE AND ACCELERATED TESTING OF RUBBER-TO-METAL VULCANIZED-BONDED ASSEMBLIES	5. TYPE OF REPORT & PERIOD COVERED Technical Report, Jul 74 - Jun 75,
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 John A. Williams	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS CDR, Rock Island Arsenal GEN Thomas J. Rodman Laboratory Rock Island, IL 61201 16	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA 1T162105AH84 PRON A1-5-R0005-01-AW-M5 AMS Code 612105.11.H8400
11. CONTROLLING OFFICE NAME AND ADDRESS Director Army Materials and Mechanics Research Center Watertown, MA 02172 11	12. REPORT DATE Aug[illegible] 1975 11
	13. NUMBER OF PAGES 34
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 34 p.	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

DDC

NOV 28 1977

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

1. Rubber-to-metal vulcanized bonds
2. Environmental exposure
3. Accelerated testing
4. Long-term storage

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this work was to determine the environmental resistance of rubber-to-metal vulcanized bonds and to develop the means of predicting this environmental resistance through accelerated testing.

Four commonly used elastomers were vulcanized-bonded to steel and aluminum substrates. Butadiene/acrylonitrile and ethylene propylene terpolymer rubber-to-metal vulcanized bonds showed a severe loss in bond strength in long-term envi-

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ronmental exposure and in accelerated testing. Butadiene/styrene and neoprene rubber-to-metal vulcanized bonds showed no significant loss in bond strength in long-term environmental exposure or in accelerated testing. Thus a degree of correlation between the results of long-term outdoor tests and short-term accelerated tests was established.

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OBJECTIVE:

The purpose of this work was to determine the resistance of rubber-to-metal vulcanized bonds to long-term storage and environmental exposure, and to develop accelerated methods for use in predicting this resistance.

BACKGROUND:

The most effective method of securing rubber to metal with sufficient strength to withstand the shear-and-peel forces encountered in many weapon applications is that of bonding the rubber to the metal at the time that the rubber is being vulcanized. This is known as vulcanized bonding. Examples of such bonds are those of rubber coatings on the aluminum M60 machine gun components, shock isolator and recoil adapter on the GAU 2B/A Minigun, rubber pads for all tracked vehicles, shock mounts for numerous shipping containers, and many small components for weapon accessories such as the rubber stop on the target holding-mechanism.

Personnel of the Research Directorate, GEN Thomas J. Rodman Laboratory, are aware that rubber-to-metal bonds on numerous weapon component spare parts have failed after a relatively short time in storage. Very little published data are available on the resistance of the rubber-to-metal vulcanized bonds to long-term storage or environmental exposure. These bond failures on replacement parts and the lack of data in this area demonstrate the need to develop the ability to predict the long-term storage or outdoor life of vulcanized bonds.

The development of the ability to predict vulcanized bond life during long-term storage and to improve the resistance of these bonds to environmental exposure will lead to significant advances in the state of the art. The Army will benefit because of the wide range of weapon applications in which vulcanized bonding is essential. Longer storage life for these weapon components will result in a tremendous savings in cost to the Army by lower replacement rates for these spare parts.

APPROACH:

Both steel and aluminum substrates were used in this study. Metal surfaces were prepared as prescribed in ASTM D429.[1] Only bonding agents

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[1] 1974 Annual Book of ASTM Standards, Part 37 Rubber Test Methods, American Society of Testing and Materials, Philadelphia, Pennsylvania

known to produce strong vulcanized bonds were employed. Four elastomers commonly used in weapon components were chosen for the study. These elastomers are the general-purpose rubbers butadiene/styrene and ethylene propylene terpolymer, and the oil-resistant nitrile and chloroprene rubbers. Vulcanized bonded specimens were prepared for outdoor exposure at Panama and at Rock Island for periods of six months, one,two, and three years. Another set of specimens was stored indoors at Rock Island for the same time periods. Standard methods of laboratory exposure used to accelerate the deterioration of rubber were screened to determine if these methods could be used to accelerate the deterioration of the bonded specimens. Methods B and C of ASTM D429 were used to measure the strength of the vulcanized bonds. Method B is a 90° peel test in which bond failure occurs between the rubber and metal substrate in a peeling action, and is measured in pounds per inch. Method C is a test in which the metal substrate is cone-shaped and in which bond failure begins at the points of the cones and proceeds until completion. Test results from conical specimens are measured in pounds.

The disadvantage of the 90° peel test is that, if the vulcanized bond has greater strength than that of the rubber, the rubber will tear before bond failure begins. With conical specimens, the vulcanized bond will usually fail before the rubber tears; in which case, the true bond-strength is obtained.

The type of failure that occurs during the evaluation of the bonds is indicated in the tables that follow. RC indicates failure at the rubber and cover coat interface; CP indicates failure at the cover coat and metal primer interface; M indicates failure at the metal primer and metal interface; R indicates that the rubber has failed, but no real value is given for the vulcanized bond strength.[2]

RESULTS AND DISCUSSION:

Formulations and physical properties of the elastomers used in the preparation of all vulcanized bonded specimens are shown in Table 1. These rubber compounds were specially formulated for weapon applications and not for ease of bonding. For example, the butadiene/styrene-based compound (S242) contains 5 parts/100 rhc UOP88 antiozonant and 1 part Heliozone wax, ingredients which impart ozone resistance to the rubber, but which detract from bondability. Similarly, the butadiene/acrylonitrile-based rubber compound (N200) contains 25 parts/100 rhc of plas-

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[2] Peterson, C. H., "Rubber to Metal Bond Failures," Rubber Age, Vol. 93, No. 6, p. 129, September 1963.

ticizer, even though the plasticizer makes the rubber more difficult to bond. The plasticizer is used to impart good flexibility at -40°F.

The results of long-term exposure indoors and outdoors at Rock Island and outdoors in Panama for the four elastomer types of bonded assemblies are shown in Tables 2 through 5, inclusive, and Figures 1 through 8, inclusive. The tabular data include the pounds required to break the bonded assemblies, both peel and conical, and also include the type of failure. The figures present the pounds required to break the conical assemblies, both aluminum and steel. The data for the peel assemblies were not shown graphically because these data, in most cases, represent failure within the rubber rather than failure at the bond line.

Data for butadiene/styrene bonded assemblies are given in Table 2 and Figures 1 and 2. No significant reduction in bond strength was noted, even after two years' exposure. The bond strengths of the conical specimens (steel and aluminum) increased, probably due to increased crosslinking of the rubber and bonding agent. The peel specimens also undoubtedly aged; but, because these specimens failed within the rubber rather than at the bond, true bond strengths could not be ascertained. The superiority of the conical specimens over the steel specimens in providing a truer measure of strength of bond is shown by these data.

The exposure of ethylene propylene bonded assemblies resulted in the data shown in Table 3 and Figures 3 and 4. Significant decreases in bond strengths are clearly indicated for the 90° peel specimens, both steel and aluminum, after two years indoors and outdoors at Rock Island and after two years at Panama, with steel showing complete bond failure during exposure. The conical aluminum specimens remained unchanged at all three sites, while the steel conical specimens showed a complete loss in bond strength after two years at Panama and a large, 57 percent, decrease after two years outdoors at Rock Island.

From the data in Table 3, note that the type of failure changed from rubber/cover coat interface to metal/metal primer interface as the exposure time and severity of conditions at the test site increased. For example, steel conical specimens showed 23 percent metal-primer interface failures after one year outdoors at Rock Island, 40 percent similar failures after one year at Panama, 92 percent failures after two years' exposure at Rock Island, and 100 percent after two years at Panama.

Results for neoprene rubber-to-metal assemblies are shown in Table 4 and Figures 5 and 6. Changes in the bond strengths were not large, even after two years outdoors at Rock Island and Panama.

The results of long-term exposure on butadiene/acrylonitrile bonded assemblies are given in Table 5 and Figures 7 and 8. Clearly, these assemblies "suffered" greater loss in bond strength than did any of the other three types of assemblies. Exposure at Panama was extremely detrimental. The steel peel specimens separated during the second six-month period, while the aluminum peel specimens lost virtually all bond strength at the end of one year.

After data had been obtained showing the effect of long-term exposure on bond strength, attempts were made to develop an accelerated test that would produce comparable changes in bond strength.

Three methods of accelerating failure were attempted. The first consisted of exposing conical specimens to dry heat in a circulating air oven and comparing the bond strength after exposure to the original strength. The second method involved the exposure of conical specimens over water in a closed jar at an elevated temperature, again comparing bond strengths before and after exposure. The third method was the same as the first or second, except that the conical specimens were elongated 50 percent of the distance between the metal cones. With the ASTM D429, Method C, the conical specimens have to be molded in such a manner that the distance between the tips of the metal cones shall be 0.47 ± 0.02 inch. Thus, the specimens were elongated about 0.23 inch. The elongation was achieved by bolting the specimen between two steel plates which were then separated a distance of 0.23 inch and kept separated with a metal spacer. Time permitted only the evaluation of steel specimens with the above-mentioned methods.

The results of the accelerated testing of conical specimens of butadiene/styrene rubber, vulcanized-bonded to steel, are shown in Table 6 and Figure 9. These data show that bond strengths increased under all conditions of test, probably due to increased crosslinking or aging of the rubber.

Data obtained from the accelerated testing of ethylene propylene terpolymer rubber-to-steel vulcanized-bonded assemblies are shown in Table 7 and Figure 10. In all but one case, the specimens aged over water showed a loss of bond strength while those aged in air showed no loss. The stressed specimens, aged over water, showed a rapid change in type of bond failure from rubber/rubber cement interface to metal/metal primer interface bond failure after only 70 hours in test. The bond strength decreased 10 percent after 70 hours and 29 percent after 7 days of testing. After 14 days, bond strength decreased by 32 percent; but the metal surface, where bond failure occurred, indicated that a rapid loss of bond strength could be expected with continued exposure.

Results of testing butadiene/acrylonitrile rubber-to-steel vulcanized bonded assemblies are shown in Table 8 and Figure 11. Significant changes in bond strength occurred after 70 hours over water. At seven days, the unstressed specimens began to show a change in type of bond failure with metal/metal primer bond failure beginning to appear. The stressed specimens over water showed a greater change with a 98 percent metal/metal-primer interface bond failure after seven days and a bond strength loss of 26 percent. After 14 days, both stressed and unstressed specimens showed a 100 percent metal/metal-primer interface bond failure. At 14 days, bond strength loss was 53 percent for the unstressed and 66 percent for the stressed specimens.

The attempt to improve the hydroltyic stability of vulcanized bonds by use of zinc phosphate coated steel substrates is shown in Table 9 and Figures 12 and 13. The data show that no significant improvement in the ethylene propylene terpolymer bonded assemblies was achieved. The nitrile-bonded assemblies with the use of the zinc phosphate coated steel showed a greater loss of bond strength than the bonded assemblies with the untreated steel. The zinc phosphate coating is believed to provide paths for the moisture to penetrate from the bond edge, paths that are not present on the untreated steel surface.

Results of the tests conducted on bonded assemblies exposed to heat, heat and humidity, to heat and stress, or to humidity, heat, and stress are summarized as follows:

1. Dry heat alone or the combination of dry heat and stress did not result in reduced bond strength after 14 days exposure. In fact, bond strengths generally increased under these conditions, probably because of increased crosslinking. Many rubber compounds based on SBR are not particularly resistant to oxidative aging.

2. Heat and humidity or the combination of heat, humidity, and stress caused reductions in bond strengths to occur within 14 days or less for specimens made from butadiene/acrylonitrile and ethylene propylene, but not for specimens of butadiene/styrene. Reduction in the strength of bond probably took place in the case of the latter polymer, but was overshadowed by the increase in strength resulting from additional crosslinks formed by the heat.

3. The test involving heat, humidity, and stress may be useful in predicting the life of bonded assemblies. A comparison of the results from this type of exposure to the results obtained from long-term natural exposures show some correlation. Butadiene/styrene rubber-to metal vulcanized-bonded assemblies showed no loss in bond strength after two years' exposure outdoors at Rock Island or after 14 days in the accelerated test. Ethylene-propylene-terpolymer rubber-vulcanized bonds showed a decrease in bond strength after one year's exposure outdoors at Rock Island, and showed a similar slow decrease in the accelerated test. Butadiene/acrylonitrile rubber-to-metal vulcanized bonds showed a severe loss of bond strength when exposed outdoors at Rock Island and at Panama. This severe loss of bond strength was also demonstrated in the accelerated test.

Means other than those in which heat and humidity are used were sought to accelerate the breakdown of vulcanized bonds. Two dynamic test devices were designed and built with the expectation that reduction in bond strength could be achieved by dynamic fatigue. The first tester rotates one end of a bonded conical specimen 45 degrees to the left and to the right of center; the other end of the specimen is firmly clamped. Either tension or compression may be applied to the specimen while it is being flexed in torsion at a rate of 300 cpm. The bond strength of the specimen is measured in the usual manner after cycling and is compared with the original strength.

The results obtained with this tester were below expectation. Vulcanized bonded specimens of butadiene/acrylonitrile rubber, which had performed so poorly outdoors and under high humidity, showed no significant reduction in bond strength after 250,000 cycles, even when elongated 50 percent. The other types of polymers were not tested with this device.

The second tester was made from a De Mattia flexing machine, which is described in ASTM D430 on dynamic testing of rubber products. The positions of the stationary and movable grips relative to each other were adjusted to accommodate the conical specimen. The lengths of the eccentric arm and the connecting rod were adjusted to provide several lengths of stroke which would elongate the conical specimen to varying amounts.

The results obtained with the modified De Mattia tester were quite promising, even though the number of tests performed was limited. The most important series of tests involved the vulcanized bonded Neoprene specimens (steel) described earlier. These specimens were tested under three different extensions, approximately 50, 100, and 200 percent. At the low extension, no bond failures resulted during 175,000 cycles, and the bond strength after this number of cycles was unchanged from the original value. At 100 percent extension, the specimens failed within the rubber after 16,850 cycles. At the highest elongation, rubber failure occurred at 3,000 cycles. The test reproducibility was good. The 16,850 cycle failure mentioned above was the average of twenty tests which ranged from 8,950 to 33,200 cycles, with results of ten tests falling within a range of only 4,000 cycles.

One other series of tests with the De Mattia tester and the Neoprene specimens is here reported. The specimens were bonded with vulcanizing agents known to produce weak bonds. In these tests, failures occurred <u>at the bond</u> after only 3500 cycles. These results were promising and indicated that, if the severity of the test can be increased, failure in the rubber might be replaced by bond failures. Three means of increased severity are quickly called to mind: (1) the increasing of cyclic rate, (2) the increasing of the extension, (3) the performing of the dynamic test after exposure to high humidity or even in the presence of high humidity.

CONCLUSIONS:

Environmental exposure data and accelerated humidity test data can be compared to show that both have the same effect on vulcanized bonded assemblies. Butadiene/styrene rubber-to-metal vulcanized bonds show no loss in bond strength after two years outdoors at Rock Island or after 14 days in the hydrolytic stability test in which specimens are stressed and exposed to 212° F over water. EPDM and nitrile vulcanized bonds exhibited changes in type of bond failure and a decrease in bond strength in both accelerated and long term tests. EPDM vulcanized bonds exhibited a slow decrease in bond strength in environmental exposure and in the accelerated test, while nitrile vulcanized bonds exhibited a severe loss of bond strength in both instances. Data obtained from this accelerated testing can be used to enable one to select the bonding agent system suitable for the task required of the vulcanized bonded assembly.

RECOMMENDATIONS:

The modified De Mattia tester developed under this study should be used as the starting point for an MTT project. The goal of the MTT project would be to improve this test device to the extent that it would, in a matter of hours or days, provide data on the strength of vulcanized bonds with which the results, obtained during long-term exposure, would be correlated.

TABLE 1
ELASTOMERS USED IN THE VULCANIZED BONDING OF RUBBER TO METAL

		Parts by Weight		
COMPOUNDING INGREDIENTS	E57	S242	M115	N200
Nordel 1040 (EPDM)	100			
Stereon 700 (SBR)		100		
Neoprene WD (CR)			100	
Paracril AJ (NBR)				85
Paracril B (NBR)				15
Philblack N550	45			
Philblack N220			40	75
Philblack N110		50		
HiSil 233				20
Necton 60	20	20	20	
Tributoxyethyl phosphate				10
Trioctyl phosphate				15
Dioctyl Sebacate			20	
UOP-88		5		
Age Rite Resin D		2.5		1
Akroflex CD			3	
Heliozone		1	3	
Stearic Acid	1			1
Zinc Oxide	5	3	5	5
Magnesium Oxide			4	
Sulfur	0.5	2		
Altax	1			3
Santocure		0.8		
Methyl Tuads	2			1.5
Ethyl Tuads				1.5
Na-22			1	
Physical Properties				
Tensile Strength, psi	1650	2220	2760	2070
Elongation, %	580	630	340	320
Hardness, Shore A	51	59	63	68
Low Temperature Flexibility, ASTM D1043, Temp. where Young's Modulus is 10,000 psi, °F.	-50	-92	-52	-48
70 hrs/212°F/ASTM #3 Oil: Volume change, %	-	-	+45	+23
Compression Set, ASTM D395, Method B, 22 hrs @ 158°F, %	14	-	11	10

TABLE 2

ENVIRONMENTAL EXPOSURE OF BUTADIENE/STYRENE RUBBER-TO-METAL VULCANIZED BONDED-ASSEMBLIES

	Method B, 90° peel, lb/in.		Method C, Conical, lb	
	Substrate		Substrate	
	Steel	Aluminum	Steel	Aluminum
Original	157 R	159 R	220 RC	258 RC
6 Months, indoors at RI	165 R	166 R	323 RC	311 RC
One year, indoors at RI	167 R	166 R	351 RC	347 RC
Two years, indoors at RI	168 R	168 R	368 RC	387 RC
6 Months, outdoors at RI	160 R	158 R	326 RC	346 RC
One year, outdoors at RI	141 R	135 R	301 RC	295 RC
Two years, outdoors at RI	168 R	165 R	338 RC	367 RC
6 months at Panama	149 R	154 R	297 RC	298 RC
One year at Panama	141 R	138 R	314 RC	337 RC
Two years at Panama	173 R	161 R	380 RC	404 RC

Primer: Thixon P-5

Cover Cement: Thixon CB-3

TABLE 3

ENVIRONMENTAL EXPOSURE OF ETHYLENE PROPYLENE TERPOLYMER RUBBER-TO-METAL VULCANIZED BONDED-ASSEMBLIES

	Method B, 90° peel, lb/in.		Method C, Conical, lb	
	Substrate		Substrate	
	Steel	Aluminum	Steel	Aluminum
Original	137 R	126 R	231 RC	218 RC
6 months, indoors at RI	116 R 73 RC 27	118 R 57 RC 43	229 RC	240 RC
One year, indoors at RI	127 R 80 RC 20	106 R 28 RC 72	245 RC	243 RC
Two years, indoors at RI	89 RC 90 R 10	87 RC 90 R 10	246 RC	244 RC
6 months, outdoors at RI	76 RC	79 RC 75 R 25	236 RC	231 RC
One year, outdoors at RI	83 RC 90 M 10	80 RC	246 RC 77 M 23	221 RC 97 M 3
Two years, outdoors at RI	73 RC 83 M 17	84 RC 83 M 17	100 M 92 R 8	257 RC
6 months at Panama	90 R 58 M 25 RC 17	75 RC 85 R 15	234 RC	234 RC
One year at Panama	44 M 57 R 43	75 RC 77 R 23	217 RC 60 M 40	217 RC 92 M 8
Two years at Panama	Bond Failure M During Exposure	86 RC 68 R 32	20 M	236 RC 95 M 5

Primer: Thixon P-5;

Cover Coat: Thixon AP1559

TABLE 4

ENVIRONMENTAL EXPOSURE OF NEOPRENE RUBBER-TO-METAL VULCANIZED BONDED-ASSEMBLIES

	Method B, 90° peel, lb/in.		Method C, Conical, lb	
	Substrate		Substrate	
	Steel	Aluminum	Steel	Aluminum
Original	82 R	100 R	378 R 90 RC 10	380 R 90 RC 10
6 months, indoors at RI	82 R	94 R	386 R 93 RC 7	300 RC 87 R 13
One year, indoors at RI	98 R	81 R	409 R 90 RC 10	372 R 55 RC 45
Two years, indoors at RI	82 R	90 R	418 R 93 RC 7	399 R 90 RC 10
6 months, outdoors at RI	98 R	98 R	386 R 90 RC 10	329 R 50 RC 50
One year, outdoors at RI	68 R	75 R	380 R 95 RC 5	319 R 57 RC 43
Two years, outdoors at RI	93 R	95 R	403 R 98 RC 2	289 RC 77 R 23
6 months at Panama	89 R	91 R	334 R 67 RC 33	356 R 73 RC 27
One year at Panama	66 R	68 R	404 R 97 RC 3	327 R 72 RC 28
Two years at Panama	84 R	81 R	369 RC 23 R 77	313 RC 43 R 57

Primer: Chemlok 205

Cover Coat: Chemlok 233

TABLE 5

ENVIRONMENTAL EXPOSURE OF BUTADIENE/ACRYLONITRILE RUBBER-TO-METAL VULCANIZED BONDED-ASSEMBLIES

	Method-B, 90° peel, lb/in.		Method C, Conical, lb	
	Substrate		Substrate	
	Steel	Aluminum	Steel	Aluminum
Original	72 R	65 R	360 R	359 R
6 months, indoors at RI	50 R	54 R	348 R 50 RC 50	349 R
One year, indoors at RI	52 R	59 R	379 R	360 R
Two years, indoors at RI	56 R	60 R	370 R	367 R
6 months, outdoors at RI	53 R	53 R	374 R	379 R
One year, outdoors at RI	21 R 98 M 2	34 R	321 R 83 M 17	342 R
Two years, outdoors at RI	31 R 67 M 33	50 R	203 M 62 R 38	358 R
6 months at Panama	16 M 68 R 32	43 M 27 R 73	165 M 50 RC 42 R 8	343 M 52 R 48
One year at Panama	Bond Failure M	11 M 75 R 25	10 M	263 M 93 R 7
Two years at Panama	during exposure	4 M	Bond Failure M during exposure	218 M

Primer: Chemlok 205

Cover Coat: Chemlok 231

TABLE 6

ACCELERATED TESTING OF BUTADIENE/STYRENE RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES

	Method C, Conical lb
Original	220 RC
70 hrs/212° F/Air	316 RC
70 hrs/212° F/over water	464 R 85 RC 15
70 hrs/212° F/Air/50% E*	417 RC 70 R 30
70 hrs/212° F/over water/50% E	299 RC 93 R 7
7 days/212° F/Air	466 R 97 RC 3
7 days/212° F/over water	438 RC 75 R 25
7 days/ 212° F/Air/50% E	342 R
7 days/212° F/over water/50% E	302 R
14 days/212° F/Air	296 R
14 days/212° F/over water	417 R 90 RC 10
14 days/212° F/Air/50% E	252 R
14 days/212° F/over water/50% E	337 RC 92 R 8

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*50% E - Specimen is elongated 50% of distance between conical points.

Primer: Thixon P-5

Cover Coat: Thixon CB-3

TABLE 7

ACCELERATED TESTING OF ETHYLENE PROPYLENE TERPOLYMER RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES

	Method C, Conical, lb
Original	231 RC
70 hrs/212° F/Air	250 RC
70 hrs/212° F/over water	255 RC
70 hrs/212° F/Air/50% E*	261 RC
70 hrs/212° F/over water/50% E	207 M
7 days/212° F/Air	305 RC
7 days/212° F/over water	209 RC
7 days/212° F/Air/50% E	248 RC
7 days/212° F/over water/50% E	165 M
14 days/212° F/Air	311 RC
14 days/212° F/over water	200 RC
14 days/212° F/Air/50% E	248 RC
14 days/212° F/over water/50% E	157 M

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*50% E - Specimens elongated 50% of distance between conical points.

Primer: Thixon P-5

Cover Coat: Thixon AP1559

TABLE 8

ACCELERATED TESTING OF BUTADIENE/ACRYLONITRILE RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES

	Method C, Conical, lb
Original	362 R
70 hrs/212° F/Air	449 R
70 hrs/212° F/over water	418 R
70 hrs/212° F/Air/50% E*	452 R
70 hrs/212° F/over water/50% E	378 R
7 days/212° F/Air	417 R
7 days/212° F/over water	370 R 95 M 5
7 days/212° F/Air/50% E	441 R
7 days/212° F/over water/50% E	272 M 98 R 2
14 days/212° F/Air	416 R
14 days/212° F/over water	170 M
14 days/212° F/Air/50% E	419 R
14 days/212° F/over water/50% E	124 M

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* 50% E - Specimens are elongated 50% of distance between conical points.

Primer: Chemlok 205

Cover Coat: Chemlok 233

TABLE 9

ACCELERATED TESTING OF BUTADIENE/ACRYLONITRILE AND ETHYLENE PROPYLENE TERPOLYMER RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES USING ZINC PHOSPHATE COATED STEEL

	Method C, Conical, lb			
	NBR		EPDM	
	Untreated	Zinc Phosphate Coated	Untreated	Zinc Phosphate Coated
Original	362 R	340 R	231 RC	253 RC
70 hrs/212° F/over water/50% E	378 R	301 R 57 M 43	207 M	225 M
7 days/212° F/over water/50% E	272 M 98 R 2	149 M	165 M	177 M
14 days/212° F/over water/50% E	124 M	37 M	157 M	176 M

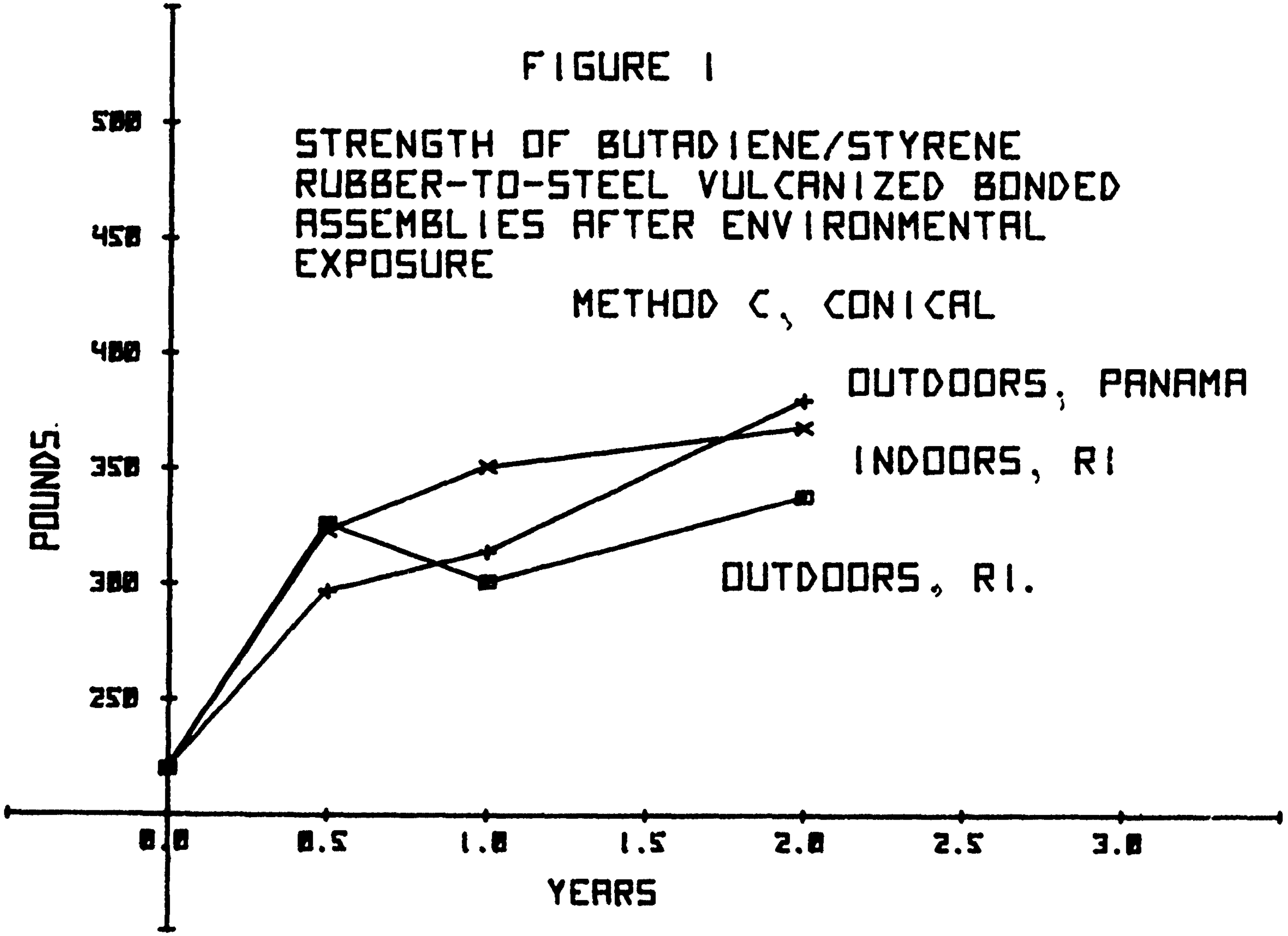


FIGURE I

STRENGTH OF BUTADIENE/STYRENE RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES AFTER ENVIRONMENTAL EXPOSURE

METHOD C, CONICAL

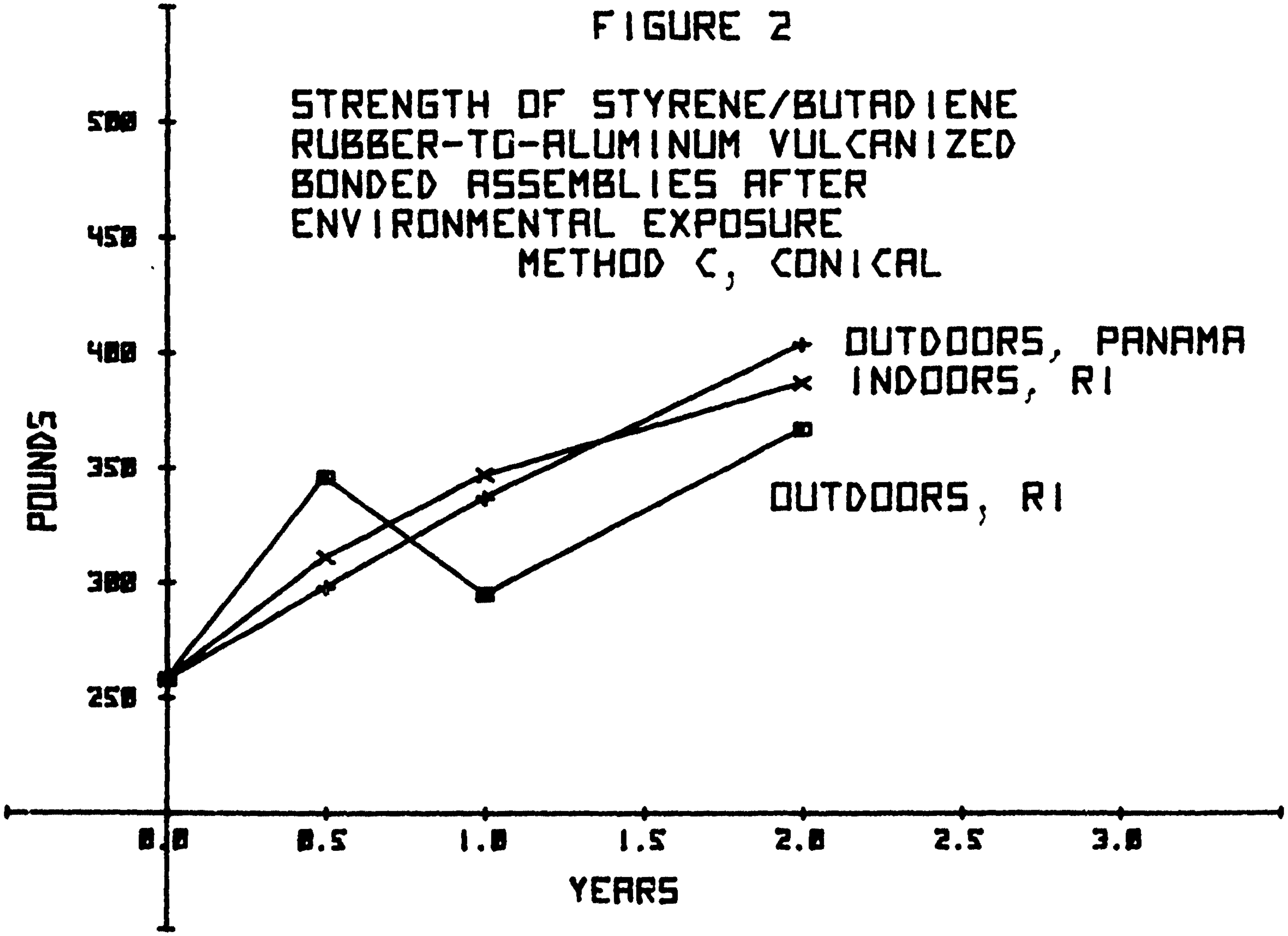


FIGURE 2

STRENGTH OF STYRENE/BUTADIENE RUBBER-TO-ALUMINUM VULCANIZED BONDED ASSEMBLIES AFTER ENVIRONMENTAL EXPOSURE METHOD C, CONICAL

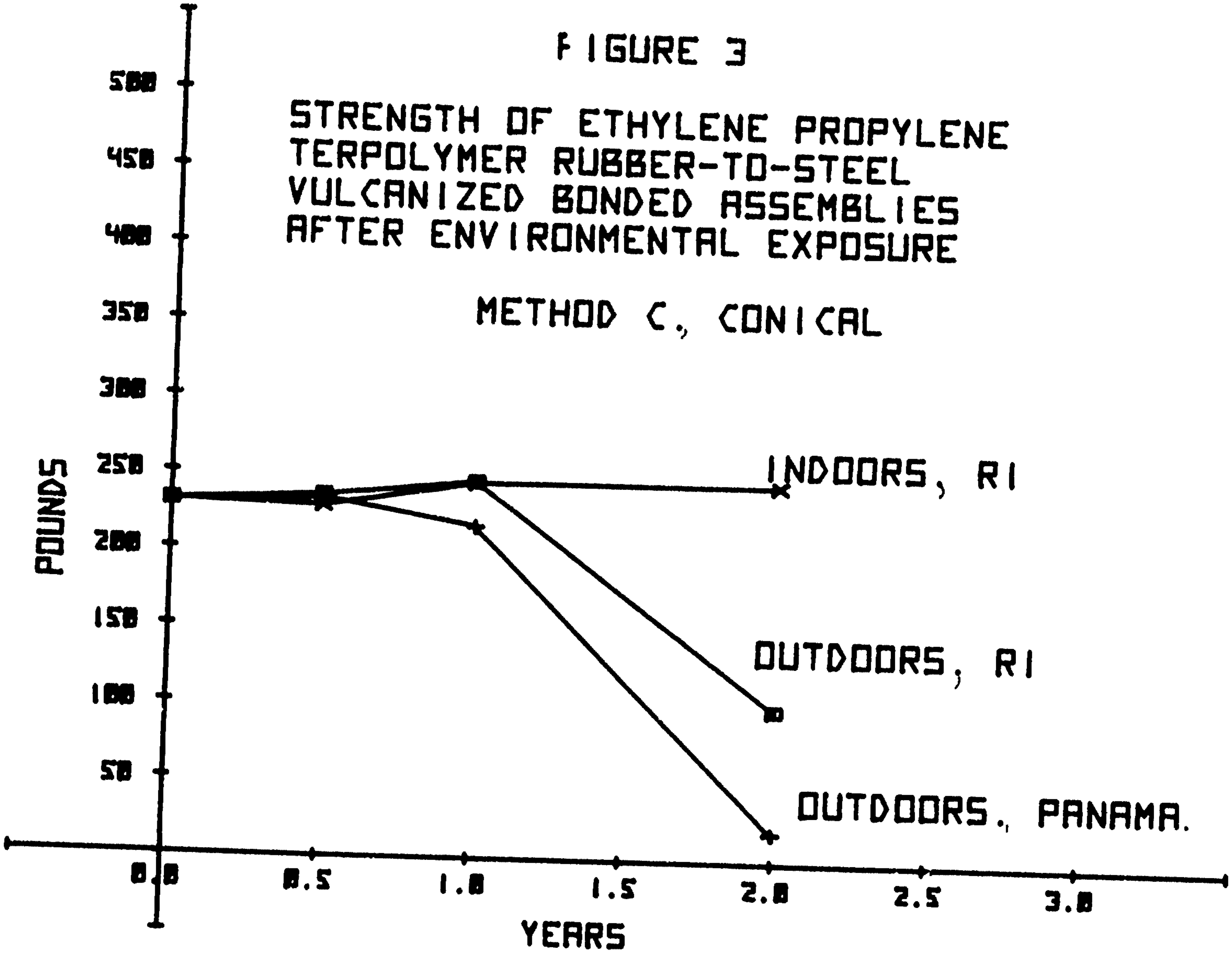


FIGURE 3

STRENGTH OF ETHYLENE PROPYLENE TERPOLYMER RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES AFTER ENVIRONMENTAL EXPOSURE

METHOD C, CONICAL

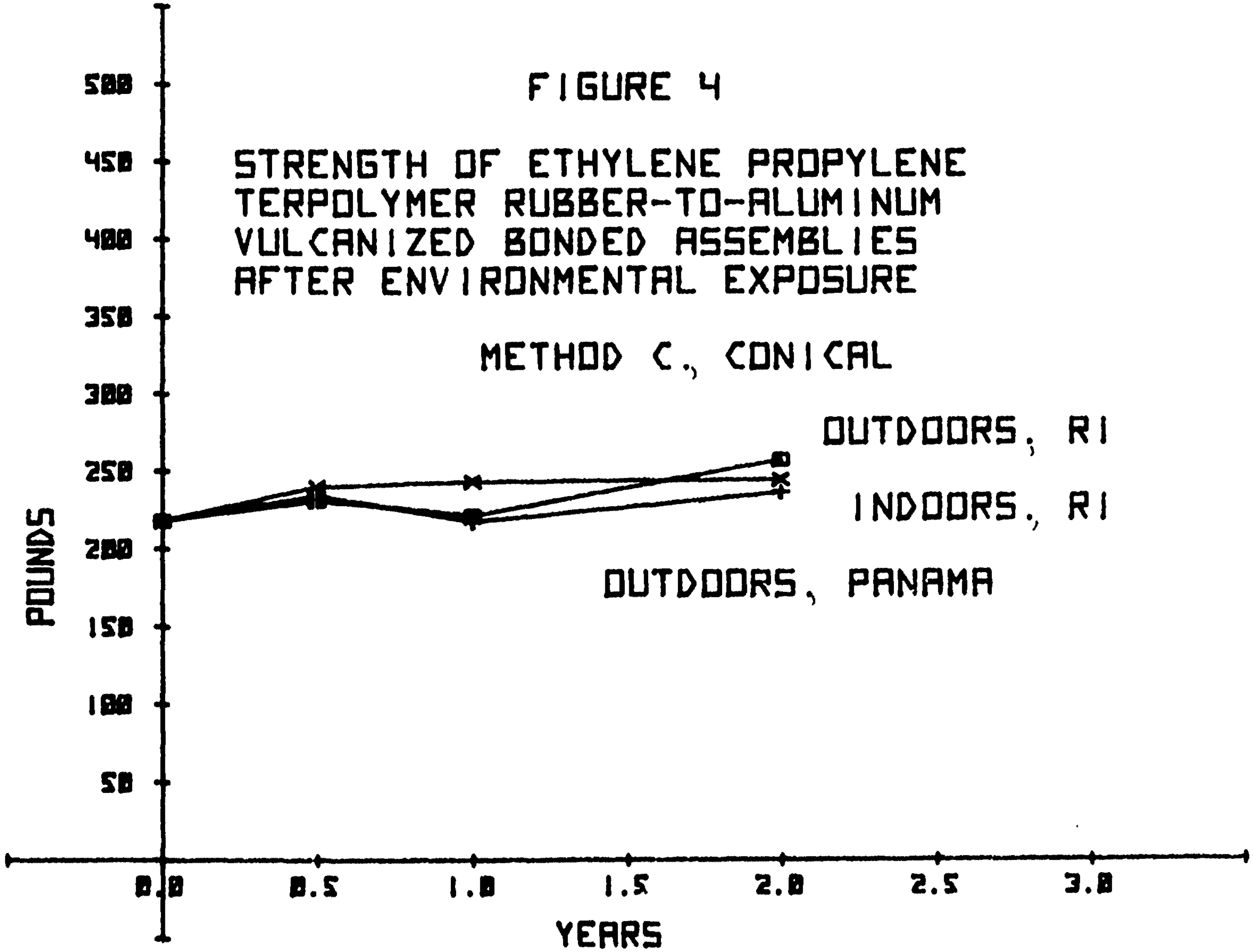


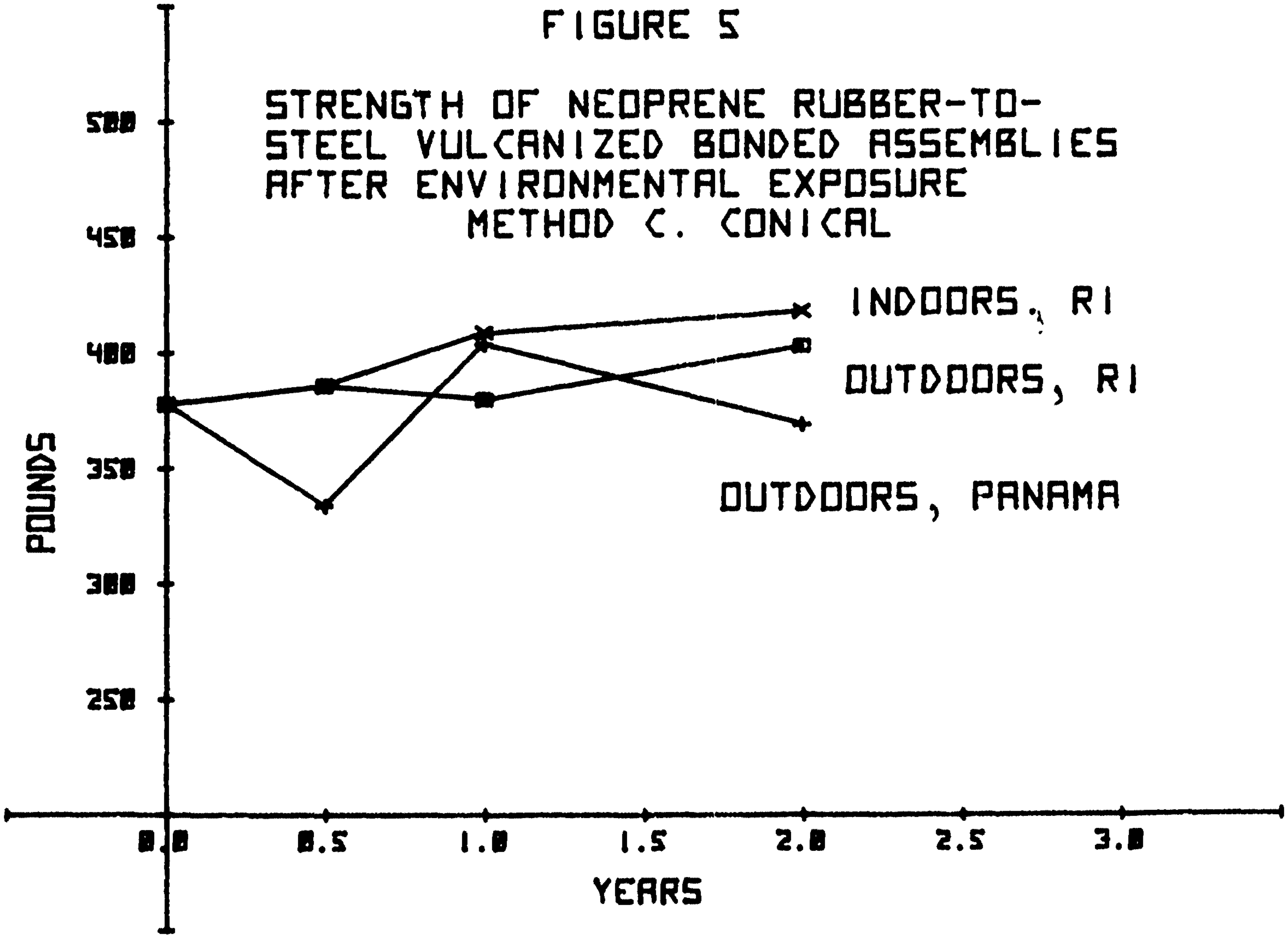
FIGURE 4

STRENGTH OF ETHYLENE PROPYLENE
TERPOLYMER RUBBER-TO-ALUMINUM
VULCANIZED BONDED ASSEMBLIES
AFTER ENVIRONMENTAL EXPOSURE

METHOD C., CONICAL

FIGURE 5

STRENGTH OF NEOPRENE RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES AFTER ENVIRONMENTAL EXPOSURE
METHOD C. CONICAL



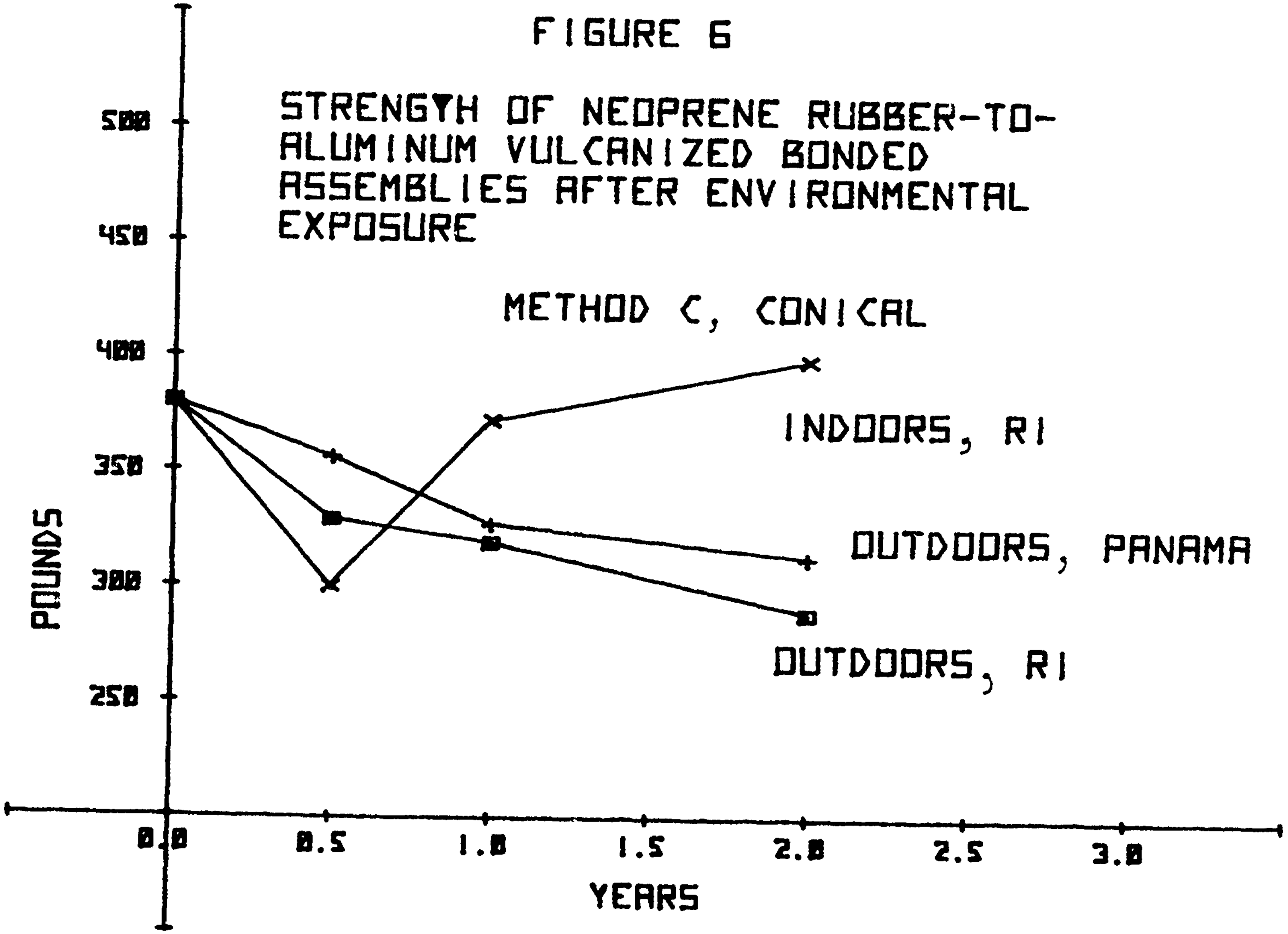


FIGURE 6

STRENGTH OF NEOPRENE RUBBER-TO-ALUMINUM VULCANIZED BONDED ASSEMBLIES AFTER ENVIRONMENTAL EXPOSURE

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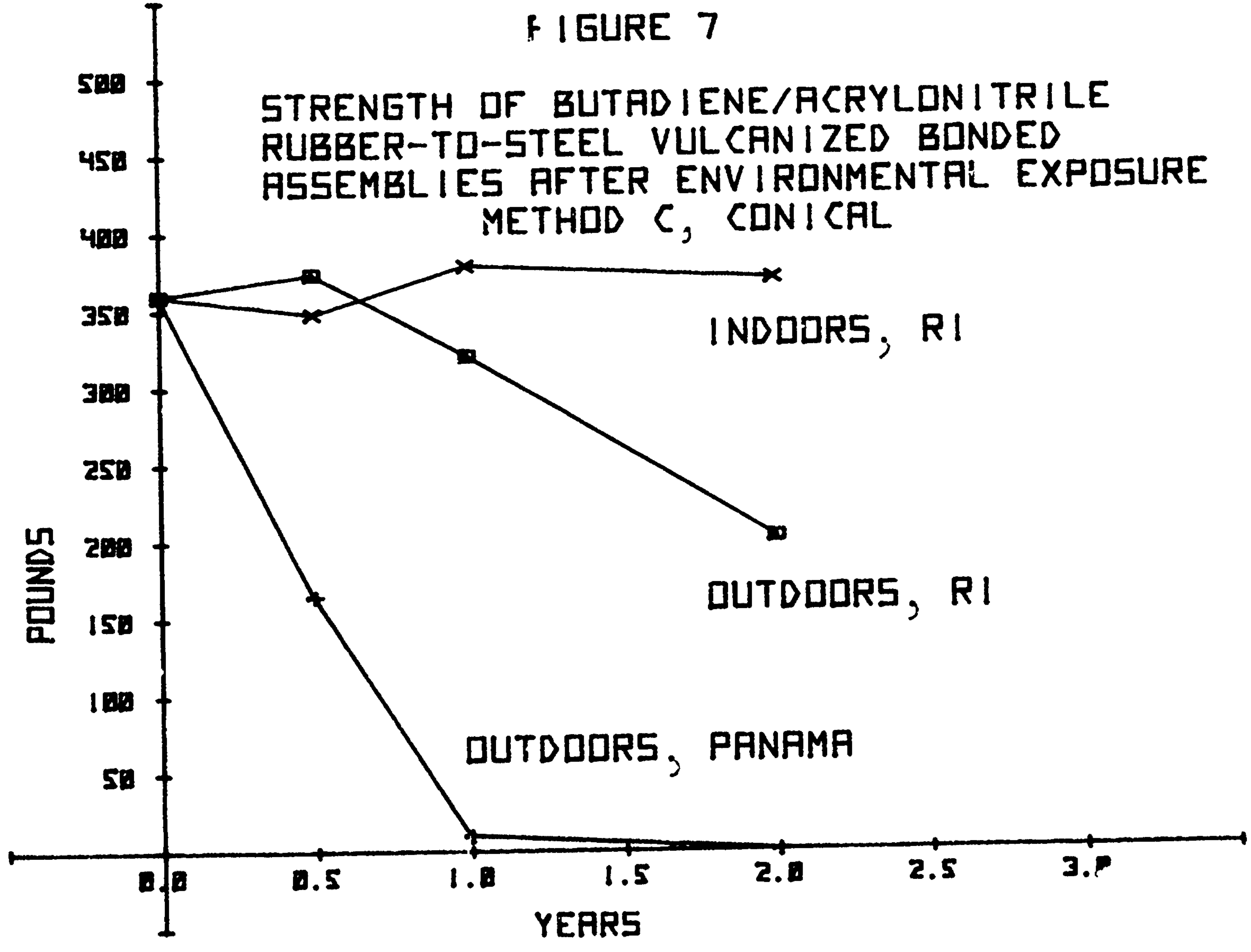

FIGURE 7

STRENGTH OF BUTADIENE/ACRYLONITRILE RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES AFTER ENVIRONMENTAL EXPOSURE METHOD C, CONICAL

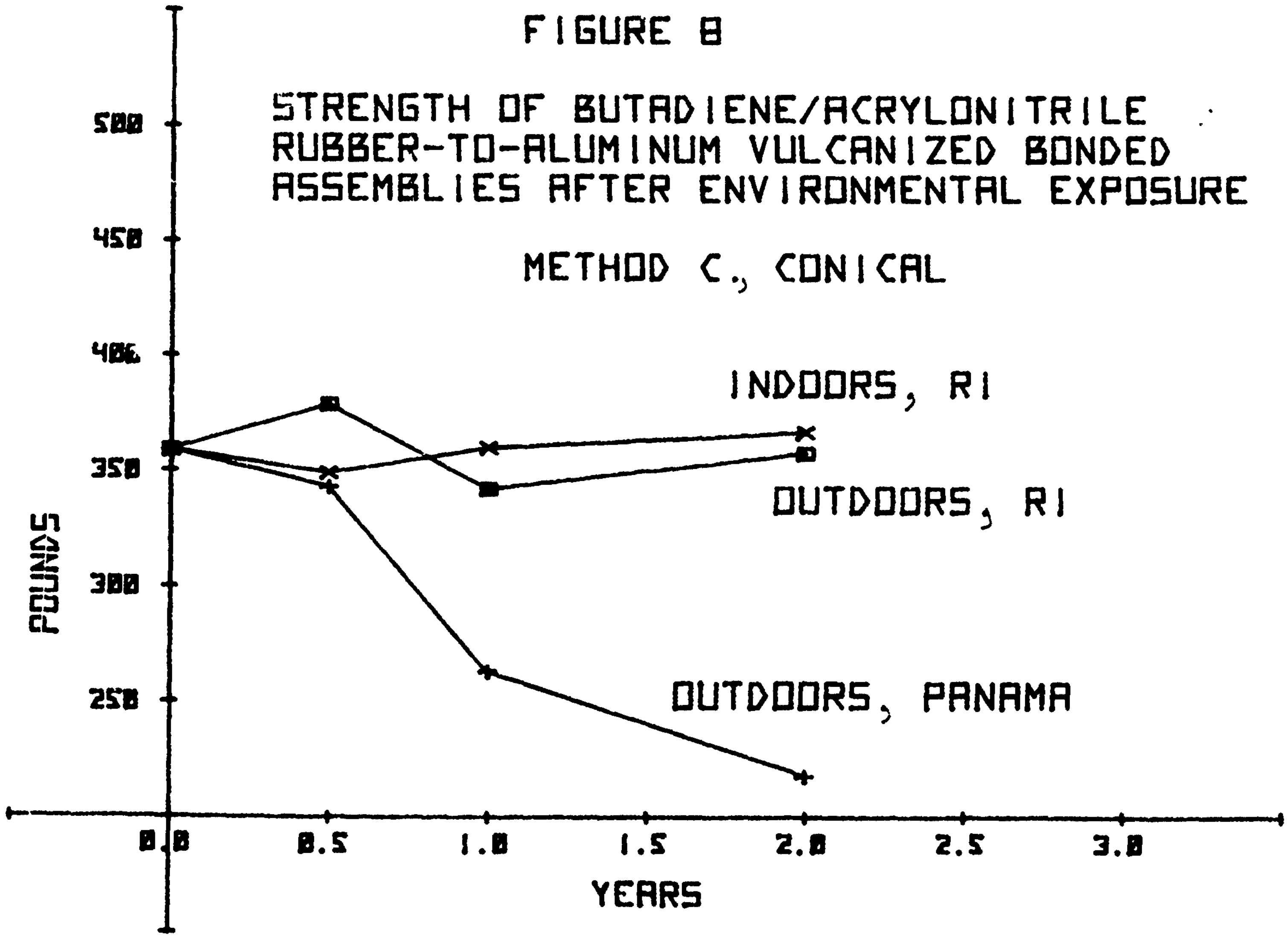

FIGURE 8

STRENGTH OF BUTADIENE/ACRYLONITRILE RUBBER-TO-ALUMINUM VULCANIZED BONDED ASSEMBLIES AFTER ENVIRONMENTAL EXPOSURE

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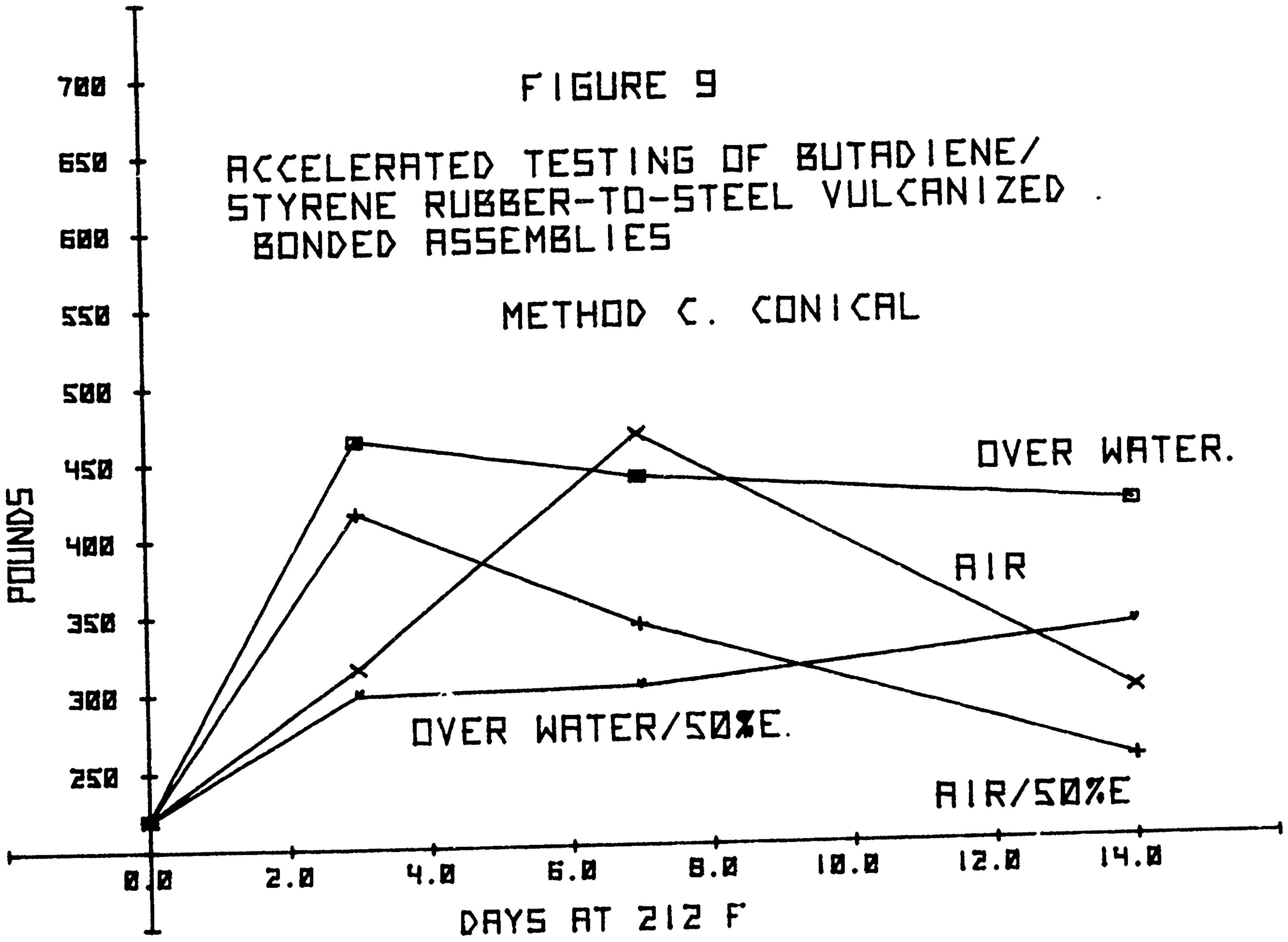

FIGURE 9

ACCELERATED TESTING OF BUTADIENE/STYRENE RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES

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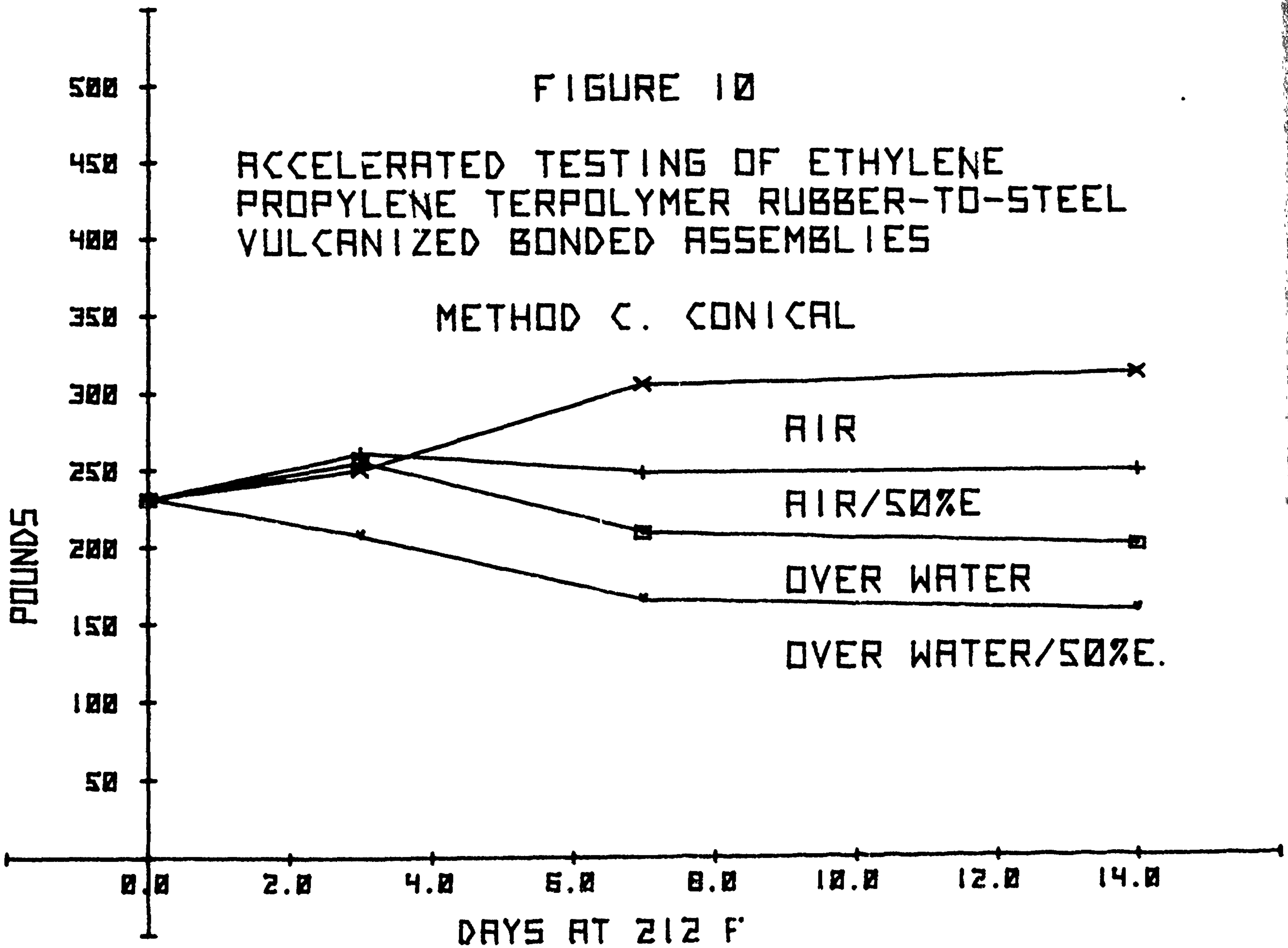


FIGURE 10

ACCELERATED TESTING OF ETHYLENE PROPYLENE TERPOLYMER RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES

METHOD C. CONICAL

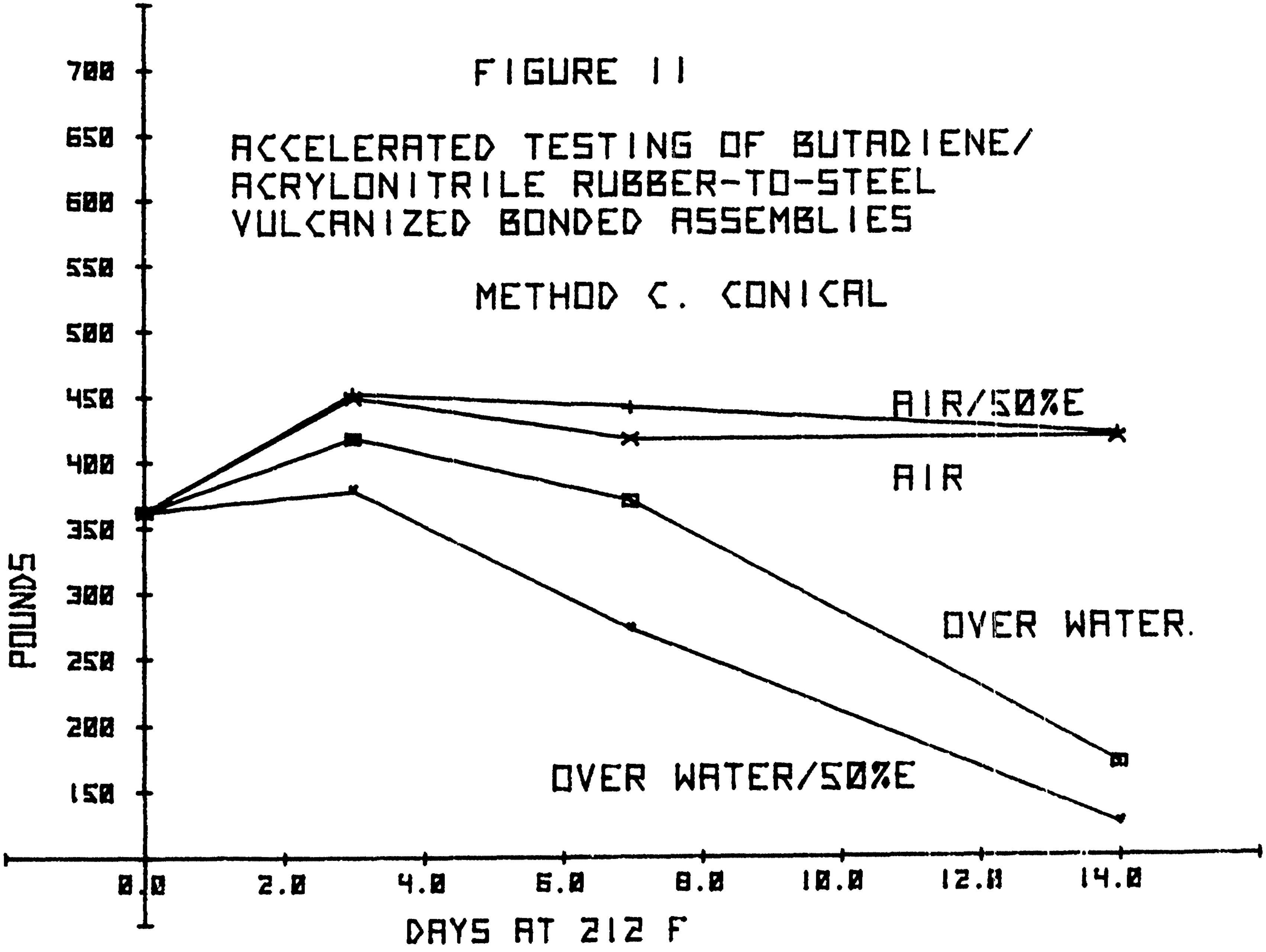


FIGURE 11

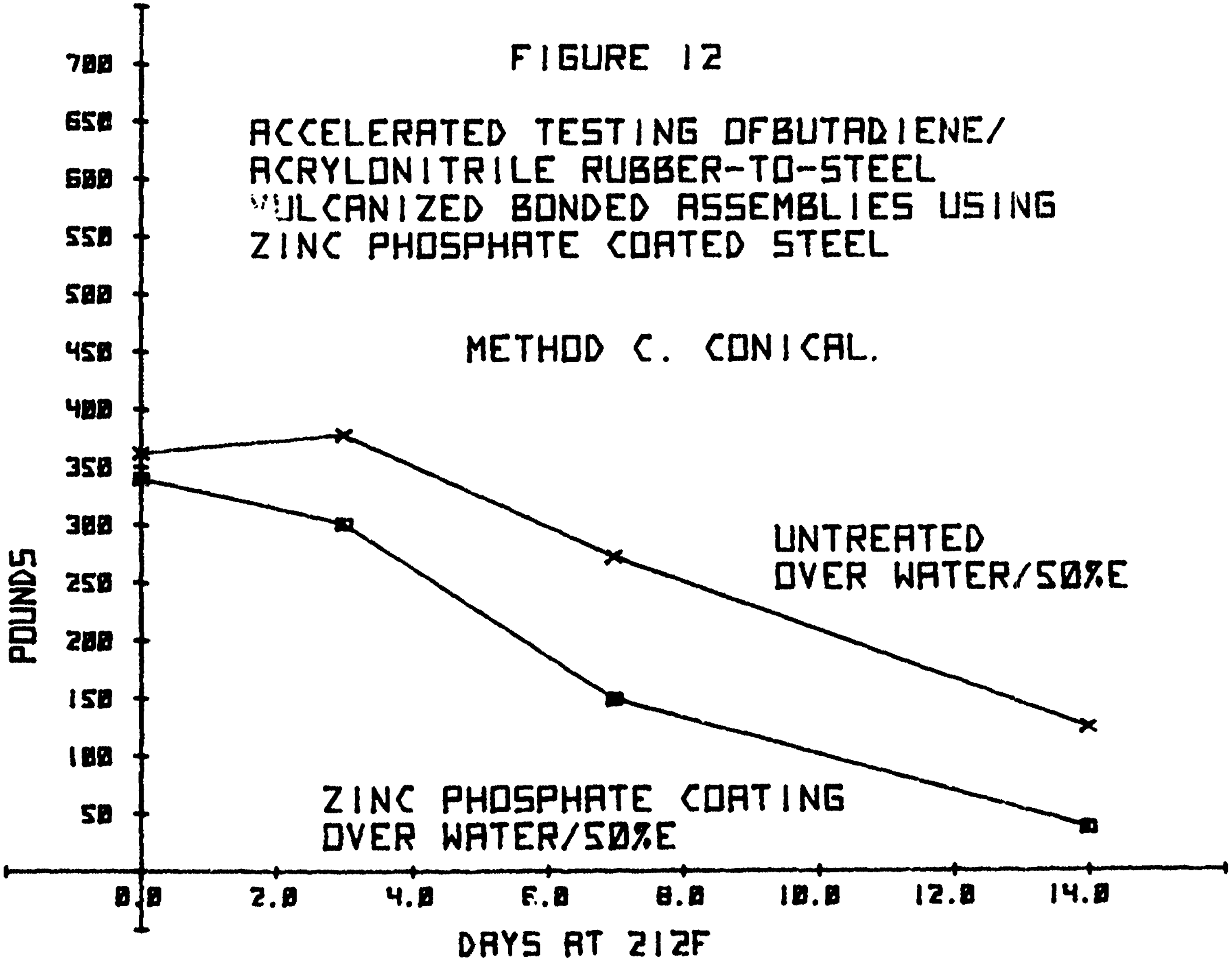
ACCELERATED TESTING OF BUTADIENE/
ACRYLONITRILE RUBBER-TO-STEEL
VULCANIZED BONDED ASSEMBLIES

METHOD C. CONICAL

FIGURE 12

ACCELERATED TESTING OFBUTADIENE/ ACRYLONITRILE RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES USING ZINC PHOSPHATE COATED STEEL

METHOD C. CONICAL.



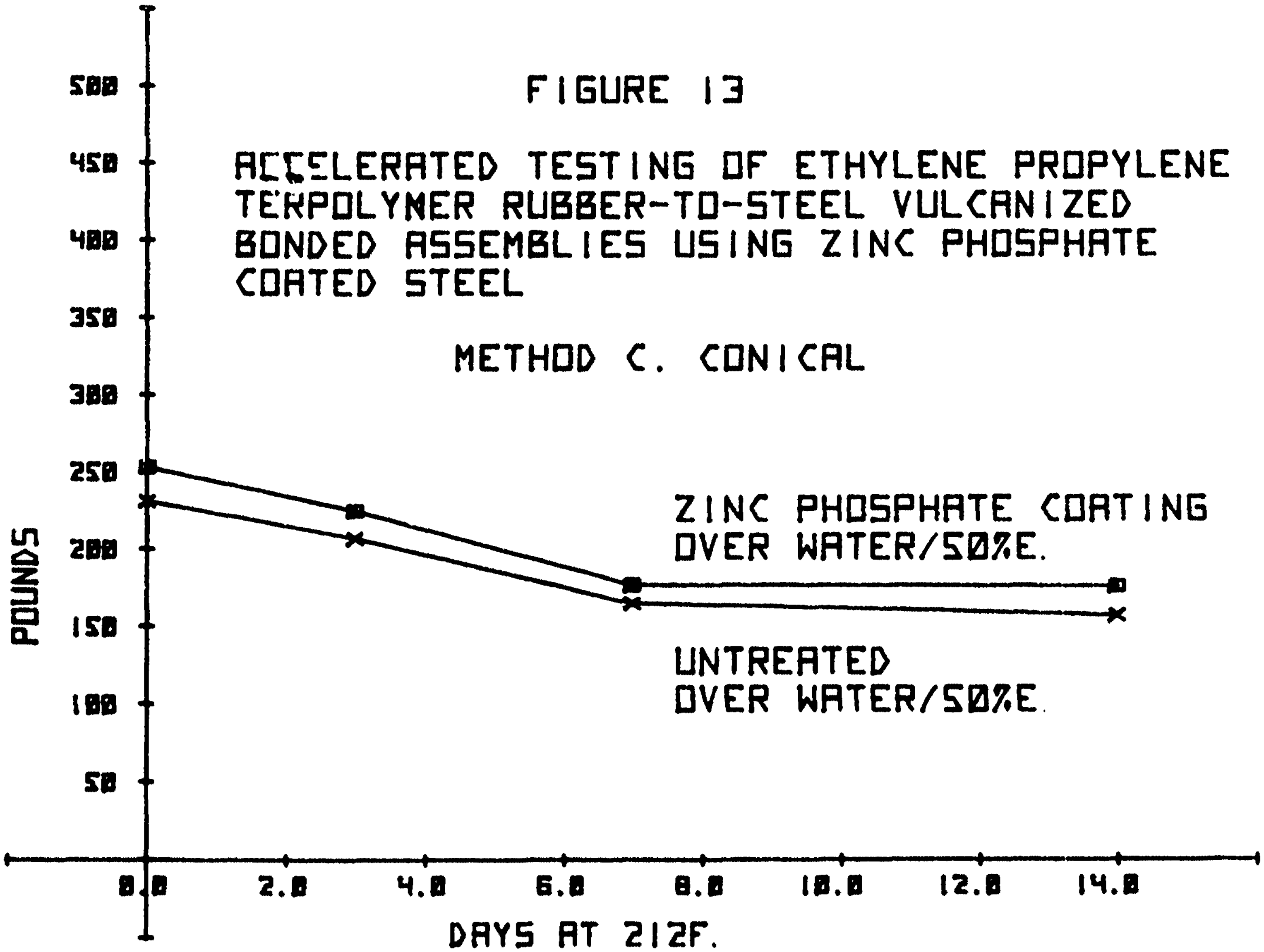


FIGURE 13

ACCELERATED TESTING OF ETHYLENE PROPYLENE TERPOLYMER RUBBER-TO-STEEL VULCANIZED BONDED ASSEMBLIES USING ZINC PHOSPHATE COATED STEEL

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