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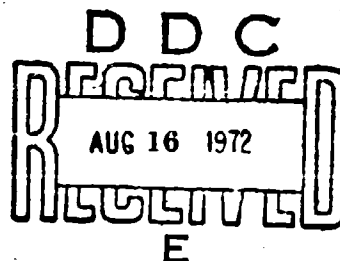
**DEVELOPMENT OF RUBBER PADS
FOR TRACKED VEHICLES**



TECHNICAL REPORT

**E. W. Bergstrom
and
J. R. Cerny**

February 1970



SCIENCE & TECHNOLOGY LABORATORY

RESEARCH & ENGINEERING DIRECTORATE

U. S. ARMY WEAPONS COMMAND

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ABSTRACT

Improvement in the wear resistance of rubber track pads was sought through compounding studies and evaluation of rubber-to-metal bonding agents. Correlation was sought between laboratory tests on the rubber component of track pads and service tests on the entire pad. Track pads fabricated from millable polyester urethanes provided improved service over that of commercial control pads. Small amounts of calcium oxide in millable polyester urethane vulcanizates eliminates the internal porosity which leads to early failure of track pads in high speed service tests but has an adverse effect on hydrolytic stability and wear resistance. Initial correlation efforts using the DeMattia and Firestone Flexometer tests are sufficiently interesting to warrant further examination. A satisfactory rubber-to-metal bonding system for millable polyester urethanes has been found.

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OBJECTIVE

The object of this work was to develop rubber track pads having improved service life, to manufacture them in pilot lot quantities for service testing, and to attempt to correlate physical properties of the rubber with service performance of the pads.

BACKGROUND

The operating life of the T97E2 track used on the M48- and M60-series tanks averages only 2200 miles because of the limitations of both its rubber and metal components. Recent reports from Vietnam indicate that in some cases pads have a service life of less than 800 miles.

The U. S. Army Tank-Automotive Command developed the T142 track with a detachable track pad to replace the T97E2 type. Tests on eight sets of T142 track at Aberdeen Proving Ground, Fort Knox, Yuma Proving Ground and the Arctic Test Board indicated that it remained operational for 5000 miles or more. However, the average life of the rubber pads ranged from only 1200 to 3600 miles and depended on the operating conditions and ambient temperatures.¹ Average life of the rubber pads was 1200 to 2200 miles at speeds of 30 mph and 1885 to 3600 miles at 20 mph.

It has been estimated that \$100,000,000 is spent each year for track suspension systems. Of this amount, approximately \$25,000,000 goes into rubber components - pads, blocks and roadwheels. Therefore, the development of an improved track pad not only would provide obvious tactical and logistical advantages for modern high speed tracked vehicles but also would lead to savings in the cost of the rubber components.

The ultimate objective of this work is to develop a 5000 mile track pad that would match the operational life of the track itself. Previous reports²⁻⁶ presented the results of compounding studies performed on numerous elastomers as well as the results of service tests conducted on experimental track pads. The results presented in this report include compounding studies, rubber-to-metal bond evaluation studies, correlation between service tests and laboratory tests, and environmental aging tests conducted since issuance of the last report.

APPROACH

Service tests of T130 and T142 track pads were arranged through the U. S. Army Tank-Automotive Command, Warren, Michigan (ATAC); and conducted at the FMC Corporation,

San Jose, California, ATAC, and Aberdeen Proving Ground, Aberdeen, Maryland (APG). The following wear rating was used to compare the performance of the rubber track pads tested:

$$\text{Volume Wear Rating} = \frac{\text{Average volume loss of commercial SBR control pads}}{\text{Average volume loss of experimental pads}} \times 100$$

Static exposure tests of T130 track pads and ASTM test pads (6 by 6 by .080 inch) in Panama were arranged through the cooperation of Dr. Leonard Teitell of the Pitman-Dunn Research Laboratories, Frankford Arsenal. Arctic exposure tests were conducted at Fort Greely, Alaska, through arrangements made with the U. S. Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland. Exposure tests were also conducted outdoors at Rock Island, Illinois.

A Number 1 Banbury mixer was used to mix compounds selected for fabrication of track pads. The Banbury-mixed compound was then transferred to a 30 inch mill for additional mixing and sheeting-out. The cooled stock was later transferred to an 18 inch mill for warmup and sheeting-out to the desired thickness for the preparation of track pad preforms from rolled stock.

The following surface preparations were performed on the metal backup plates (inserts) prior to their vulcanization bonding to the rubber preforms: degreasing, glass bead-blasting, solvent wiping, brush application of bonding agent, and drying.

Tensile strength, elongation, and modulus were determined at ambient and elevated temperatures by use of a Scott Model L-6 rubber tensile tester equipped with a Scott Model HT0 hot tensile oven and autographic recorder-controller. Each tensile specimen was placed in the grips of the tester and conditioned for a period of six minutes at temperature before being tested. All other physical properties were determined by ASTM procedures, where applicable.

Compound formulations are given in Table I.

TABLE 1

COMPOUND FORMULATIONS AND PHYSICAL PROPERTIES

Compounding Ingredients	Parts by Weight															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Milable Polyester Urethane (A)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
SBR 1500	40	40	40	40	55	55	55	55	55	55	45	45	55	45	45	45
SAP Carbon Black A																
Fine particle size silica A																
Zinc Oxide	0.2	0.4	0.2	0.2	4	3	3	3	3	3	3	4	3	3	3	3
Stearic Acid					2	1	1	1	1	1	1	2	1	1	1	1
Sulfur					2	1	0.2	0.4	0.5	0.5	0.2	2	0.2	0.2	0.2	0.2
N-cyclohexyl-2-benzothiazole sulfenamide					1.5							1.5	0.5	0.5		
Dicumyl peroxide (40% active)	7	8	7	7		4	4	4	4	4	4		4	4	4	4
N-phenylene-bis-maleimide					1							1				
Triethyldihydroquinoline					1							1				
Phenyl-beta-naphthylamine					3							3				
N,N'-diethyl-p-phenylenediamine					1							1				
Wax																
Polycarbodiimide																
Calcium oxide																
Fine particle size silica B																
Cure (minutes @ Temp. °F)																
ASTM Test Pads																
7130 or 7142 Track Pads																
Tensile strength, psi., ambient	4520	4430	4530	4310	3670	3520	2570	2750	2940	3600	3420	3630	3690	2870	3030	2760
400°F	630	650	610	480	470	660	470	420	440	430	580	280	710	800	610	270
Ultimate elongation, % ambient	500	520	450	540	410	490	625	610	400	580	620	515	500	580	400	615
400°F	340	350	340	440	200	220	270	240	150	175	290	165	240	345	135	325
Hardness Shore A	70	75	73	71	74	70	67	65	70	67	63	68	69	69	76	72
Tear, Die C, psi	240	260	225	205	170	190	260	255	160	215	180	175	175	220	150	185

*For trade names of compounding ingredients see code sheet at end of report

Lignin reinforced SBR received fully compounded from the Defense Chemical Biological & Radiation Laboratories, Shirley Bay, Ottawa, Ontario, Canada

TABLE 1 (continued)

COMPOUND FORMULATIONS AND PHYSICAL PROPERTIES

Compounding Ingredients	Parts by Weight													
	17	18	19	20	21	22	23	24	25	26	27	28	29	30
SBR 1500	75	75	75	75	75	101.5	101.5			70	70	70	70	85
Oil-black Masterbatched SBR														
Cis-Polybutadiene (A)	25	25	25	25	25	64.5	64.5			30				
Cis-Polybutadiene (B)														
High Mooney EPDM (HM-EPDM)														
70 Mooney EPDM														
140 Mooney EPDM														
Fast Curing EPDM (A)														
Fast Curing EPDM (B)														
SAF Carbon Black A	45	45	40	55	40			45	45	45	45	45	45	45
Fine particle size silica B								15	15	15	15			
Magnesium oxide	4	3	3	3	3	3	2	3	3	3	3	3	3	3
Zinc oxide	2	2	1	1	1	2	2	1	1	1	1	2	2	2
Stearic acid	2	0.2	0.2	0.2	0.2	1.5	1.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sulfur	1.5	0.5	0.5	0.5	0.5			0.5	0.5	0.5	0.5	0.5	0.5	0.5
N-cyclohexyl-2-benzothiazole sulfenamide														
N-t-butyl-2-benzothiazole-sulfenamide														
Dicumyl peroxide (40% active)	4	4	4	4	4	1	1	4	4	4.5	5	5	5	5
Resin														
Alkyl antioxidant mixture	1					5	5							
Triethyldihydroquinoline	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Phenyl-beta-naphthylamine														
6-ethoxy-1,2-dihydro-2,4-trimethyl quinoline	5					1.5	1.5							
N,N'-dioctyl-p-phenylenediamine	1													
Wax														
Cure (minutes & Temp., °F)														
ASTM Test Pads	204307	454307	454307	454307	454307	454310	454310	454307	454307	454307	454307	304307	304307	304307
T130 or T142 Track Pads														
Tensile strength, psi	3340	3220	3420	3670	3630	2930	2950	3320	3410	4060	2770	3350	3360	3180
400°F	350	620	630	760	790	450	430	--	880	960	720	--	--	--
Ultimate elongation, %	540	495	645	545	635	710	810	600	605	515	555	510	510	530
400°F	225	250	245	255	300	350	370	--	310	250	290	--	--	--
Hardness, Shore A												68	69	65
Tear, Die C, psi	190	180	185	190	230	--	210	220	230	205	210	--	--	--

TABLE 1 (continued)

COMPOUND FORMULATIONS AND PHYSICAL PROPERTIES

Compounding Ingredients	Parts by Weight										
	31	32	33	34	35	36	37	38	39	40	41
SR 1500											
Stereospecific SBR (A)	70		30								
Stereospecific SBR (D)		70									
Fast Curing EPDM (A)	30	20					15				
Cis-polybutadiene (A)			25	25							
70 Mooney EPDM			25								
High Mooney EPDM (HM-EPDM)				25							
Chlorinated butyl					100	85	100	100			
Peroxide curable butyl											
SAF Carbon Black (A)			45	45							
SAF Carbon Black (B)	55	55	15	15							
Fine particle size silica R											
EPC Carbon black					65	65	60	60			
Zinc oxide	3	3	3	3	5	5					
Stearic acid	1	1	1	1	1	1					
Sulfur	0.2	0.2	0.2	0.2	0.5	0.5		0.2			
N-cyclohexyl-2-benzothiazole sulfenamide	0.5	0.5	0.5	0.5				0.5			
Tetramethyl thiuram disulfide					1	1					
Benzothiazyl disulfide					1	1					
Dicumyl peroxide (40% active)	4	4	4	4			3	3			
Zinc salt of 2-mercaptobenzothiazole							2				
Magnesium oxide					1	1	1	1			
N,N'-diphenyl-p-phenylenediamine											
Diethyl-beta-naphthylamine	1	1	1	1	1	1	0.75	1			
Cure (minutes @ Temp., °F)	45@307	45@307	45@307	45@307	41@307	40@307	61@320	61@320	45@310	45@310	45@310
ASTM Test Pads									75@320	75@320	75@320
T130 or T142 Track Pads											
Tensile strength, psi., ambient	2460	2260	2980	3700	2420	2700	1210	700	4420	4470	3650
400°F	770	750	810	920	410	440	--	250	470	550	Blistered
Ultimate elongation, %, ambient	370	330	565	480	470	530	200	220	300	310	400
400°F	180	160	300	260	300	200	--	100	105	180	Blistered
Hardness, Shore A	70	75			70	70	60	62	77	77	77
Tear, Die C, psi	--	--	210	170	180	185	--	90	130	180	175

TABLE 1 (continued)

COMPOUND FORMULATIONS AND PHYSICAL PROPERTIES

Compounding Ingredients	Parts by Weight														
	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Milable polyester urethane (B)	100	100													
Stereospecific SBR (C)			100												
High Mooney EPDM (HM-EPDM)			30	100	100	100	70		100	100	100	100	100	100	100
SBR 1500															
Milable polyester urethane (A)															
Milable polyester urethane (D)															
Fast curing EPDM (C)							30	30							
Fast curing EPDM (D)								70							
Stereospecific SBR (B)	40	30	45	45	30	40	45	45	40	30					40
HAF carbon black															
SAF carbon black (A)															
SAF carbon black (B)															
SAF carbon black (C)															
ISAF carbon black (A)															
ISAF carbon black (B)															
SPF carbon black					30						30	50	40		
Zinc oxide															
Stearic acid	0.25	0.25	3	3		0.2	3	3							
Phenyl beta naphthylamine			2.5	1			2	2							
Sulfur			1.75	0.2			1	1							
N-cyclohexyl-2-benzothiazole			1	0.5			0.5	0.5							
sulfonamide															
Dicumyl peroxide (40% active)	5	8	3	4	7	7	5	5	7	8	5	5	7	7	5
Diisocyanate (TDI)					4	2			4		4	4			4
Polycarbodiimide	2	2													
Process oil			10	15											
Fine particle size silica (D)															
Cure (minutes @ Temp., °F)															
ASTM Test Pads															
TI30 or TI42 Track Pads															
Tensile strength, psi, ambient	454135	438405	438407	438407	438410	438410	438407	438407	438410	438410	438410	438410	438410	438410	438410
400°F	738329	738329	738329	738329	738329	738329	738329	738329	738329	738329	738329	738329	738329	738329	738329
Ultimate elongation, % ambient	3310	4370	3180	1580	5800	4530	3080	2290	4200	5590	6490	5320	5470	4730	5680
400°F	210	630	390	820	520	675	820	760	570	700	580	590	820	1170	930
Hardness, Shore A	465	370	550	470	550	465	350	310	550	400	560	515	455	320	475
Tear, Die C, psi	325	180	210	210	230	400	200	160	400	225	255	385	360	265	290
	75	77	61	72	68	70	67	74	72	69	75	83	70	72	80
	210	175	190	185	--	--	--	--	--	--	--	--	--	--	--

*Post cure 70 hrs at 212°F

TABLE I (continued)

COMPOUND FORMULATIONS AND PHYSICAL PROPERTIES

Compounding Ingredients	Parts by Weight							
	57	58	59	60	61	62	63	64
Milable polyester urethane (A)	100							
Milable polyester urethane (D)		100	100					
Isoprene				100				
Chlorosulfonated polyethylene						5		
Polyoxypropylene					100		75	
SBR 1500							25	
Cis-polybutadiene (A)						100		100
70 Mooney EPDM								40
Carboxylic Elastomer								
ISAF Carbon Black (D)	25		30					
SAF Carbon Black (A)		35		30			45	
SAF Carbon Black (B)					50			
SPF Carbon Black								
Zinc oxide				5	3		4	5
Stearic acid	0.2	0.2	0.2	3	1		2	1
N-cyclohexyl-2-benzothiazole-sulfenamide				1	1.4		1.5	
Dipentamethylene thiuram tetrasulfide						1		
Tetramethyl thiuram monosulfide								0.4
Sulfur				2.5	1.5		2	1.5
Dicumyl peroxide (recrystallized)						3.5		
Dicumyl peroxide (40% active)	7	5	8			0.5		
2,2'-methylene bis(4-methyl-6-t-butyl phenol)				1	1			
Phenyl beta naphthylamine							1	
Trimethyl dihydroquinoline							1	1
N,N'-dioctyl-p-phenylenediamine							5	
N-phenyl-N'-cyclohexyl-p-phenylenediamine								4
Wax							1	
Sb ₂ O ₃						5		
Diisocyanate (TDI)	4	4	4					
Polycarbodiimide								
Cure (minutes & Temp., °F)								
ASTM Test Pads	45/310	30/320	45/310	20/292	30/307	60/320	30/307	30/310
T130 or T142 Track Pads	75/320	75/320	150/292	75/320	75/307	105/320	65/307	75/310
Tensile strength, psi... ambient	5700	3970	5220	3960	2370	3450	2880	4370
400°F	400	700	710	--	770	790	410	730
Ultimate elongation % ambient	475	460	445	730	460	405	485	440
400°F	135	350	220	--	205	210	215	205
Hardness, Shore A	69	74	70	50	72	68	65	82

RESULTS AND DISCUSSION

Track Pads Prepared from Millable Urethanes

As previously reported,⁶ track pads prepared from millable polyester urethane (A) consistently exhibited significantly improved wear and chunking resistance when compared with SBR control pads. However, there are a number of problems associated with the use of millable polyester urethanes in general and with the one mentioned here in particular.

For example, urethane track pads have failed because of adhesive bond failures, the rubber pads actually separating from the metal insert during test and dropping off in many instances. The search for an improved rubber-to-metal bonding system has continued since that time, and satisfactory vulcanization bonding systems have been found, as will be discussed later. No track pad failures due to poor bonds have occurred in service tests since these systems have been used.

Another problem associated with the use of the millable polyester urethanes is that of their hydrolytic instability.⁷ The degradation in physical properties caused by hydrolytic attack can be delayed by the use of additives such as a diisocyanate (TDI) or polycarbodiimide (PCD), but cannot be eliminated. T130 track pads prepared from compounds with and without an additive were exposed outdoors in Panama (open sun and rain forest) and at Rock Island, Illinois, with a planned exposure period of five years. Results obtained thus far after one year of exposure are given in Table II. Significant deterioration in physical properties has occurred in the uninhibited pads, particularly at Panama. The PCD-inhibited pads show little or no change in tensile strength after exposure in the open sun at Panama and Rock Island, but the tensile strength of pads exposed in the rain forest indicates that the surface of the pads has been adversely affected by hydrolytic degradation.

Physical properties were also determined on T142 pads prepared from a polyester urethane (A) compound containing no hydrolysis inhibitor (compound 1, Table I) which were (1) molded in October 1965, tested at Yuma, and stored at ATAC until sent to this Laboratory for evaluation in January 1969; and (2) molded in June 1968, tested at APG, and stored at ATAC until sent to this Laboratory for evaluation in January 1969. These results are shown in Table III. All pads exhibited severe tensile strength

TABLE II

PROPERTIES OF POLYESTER URETHANE (A) T130
RUBBER TRACK PADS AFTER OUTDOOR AGING

Properties Tested	PCD Inhibited Pads				Exposed 1 Yr Rain Forest Panama	
	Exposed Outdoors 1 Yr Rock Island		Exposed 1 Yr Open Sun Panama		Exposed 1 Yr Rain Forest Panama	
	Section 1 from surface	Section 9 fm. approx. middle of pad	Section 1 from surface	Section 9 fm. approx. middle of pad	Section 1 from surface	Average of Sections 2 - 9
Unused Sectioned Pad (average of 9 consecutive sections - approx. 0.75" each)	4140	4380	3790	4490	2190	4510
Tensile strength, psi	2340	2360	2030	2220	1660	1980
Modulus at 300%	450	480	455	485	350	510
Elongation, psi	73	70	68	70	70	70
Ultimate Elongation, %						
Hardness, Shore A						

Properties Tested	Uninhibited Pads (No Hydrolysis Additive)				Exposed 1 Yr Rain Forest Panama	
	Exposed Outdoors 1 Yr Rock Island		Exposed 1 Yr Open Sun Panama		Exposed 1 Yr Rain Forest Panama	
	Section 1 from surface	Section 9 fm. approx. middle of pad	Section 1 from surface	Section 9 fm. approx. middle of pad	Section 1 from surface	Section 9 fm. approx. middle of pad
Unused Sectioned Pad (average of 9 consecutive sections - approx. 0.75" each)	3490	3900	1400	2030	850	3000
Tensile strength, psi	1520	1670	520	600	500	890
Modulus at 300%	480	515	590	655	380	645
Elongation, psi	65	68	57	55	57	59
Ultimate Elongation, %						
Hardness, Shore A						

*pads were sliced into .075-inch slices in a direction parallel to the face of the pad; slices were numbered beginning with the outermost layer.

TABLE III

PHYSICAL PROPERTIES OF T142 POLYESTER URETHANE (A)
TRACK PADS AFTER SERVICE TESTS AT APG AND YUMA

Properties Tested	Pad 1-A		Pad 82	Pad 90
	Prepared June 1968 Tested at APG Properties determined March 1969	Both pads prepared October 1965 Tested at Yuma Properties determined March 1969		
Tensile strength, psi	3120	2410		2400
Modulus, 300% Elongation, psi	1540	910		940
Ultimate Elongation, %	550	630		630
Hardness, Shore A	61	58		58
Firestone Flexometer, Time to go from 100-200°F, 0.25 in. throw, 600 lb load, min.	3.8	4.7		4.8
Compression Modulus, psi	265	245		245

The physical properties determined originally on vulcanizates prepared from the compound used in preparing the track pads are as follows:

Properties Tested	Pads 82 and 90	
	Properties determined June 1968	Properties determined October 1965
Tensile Strength, psi	4520	4740
Modulus, 300% Elongation, psi	2040	2190
Ultimate Elongation, %	500	510
Hardness, Shore A	70	68

deterioration which points up again the need for incorporation of a hydrolysis inhibitor in polyester urethane track pads. However, even polyester urethane compounds containing hydrolysis inhibitors (TDI or PCD) are subject to severe deterioration when aged in tropical environments such as Panama, as shown in Figure 1. On the other hand, these same compounds withstand temperate (Rock Island, Illinois) and arctic (Fort Greely, Alaska) environments. More detailed results of the hydrolytic stability of polyester urethane vulcanizates may be found in References 7, 8 and 9.

A recent service test at APG on T142 track pads prepared from polyester urethanes revealed failures which appeared to be caused by internal gassing of the pads during high-speed testing on paved and gravelled roads. This gassing was duplicated in this Laboratory by use of the Firestone Flexometer. Cross sections of samples tested are compared with a failed track pad in Figure 2. The gassing of the Flexometer specimens occurred whether or not the specimens were conditioned for three days at 212°F prior to test. Thick section pieces (1 by 1 by 1-1/2 inch) of Firestone Flexometer specimens were air oven aged to determine the effect of heat alone (no dynamic flexing) on the vulcanizates. Photographs of cross sections of the specimens after aging are shown in Figures 3-5. These tests revealed the following:

1. Certain polyester urethane specimens exhibit gassing when aged at 350°F and 400°F, whereas SBR specimens show no gassing when aged at temperatures up to 400°F (Figure 3).

2. Conditioning at 212°F for three days prior to aging at 350°F reduces the gassing of a polyester urethane vulcanizate containing no hydrolysis inhibitor and completely eliminates the gassing at 350°F in a polyester urethane compound containing PCD (Figure 4).

3. Gassing was eliminated at 350°F in a polyester urethane compound which contained PCD and 5 parts/100 rhc calcium oxide (Figure 5). Unfortunately, the inhibiting action of PCD against hydrolytic attack is destroyed as shown in Table IV. Less than 5 parts of calcium oxide were ineffective in eliminating gassing at 350°F.

Thin specimens (0.075 inch) of polyester urethane vulcanizates exhibited no gassing when aged at temperatures up to 400°F. It is the opinion of this Laboratory that the failure of track pads at APG was due to a combination of high shearing stresses (due to pad design) and high-heat buildup within the rubber itself during the high-speed test.

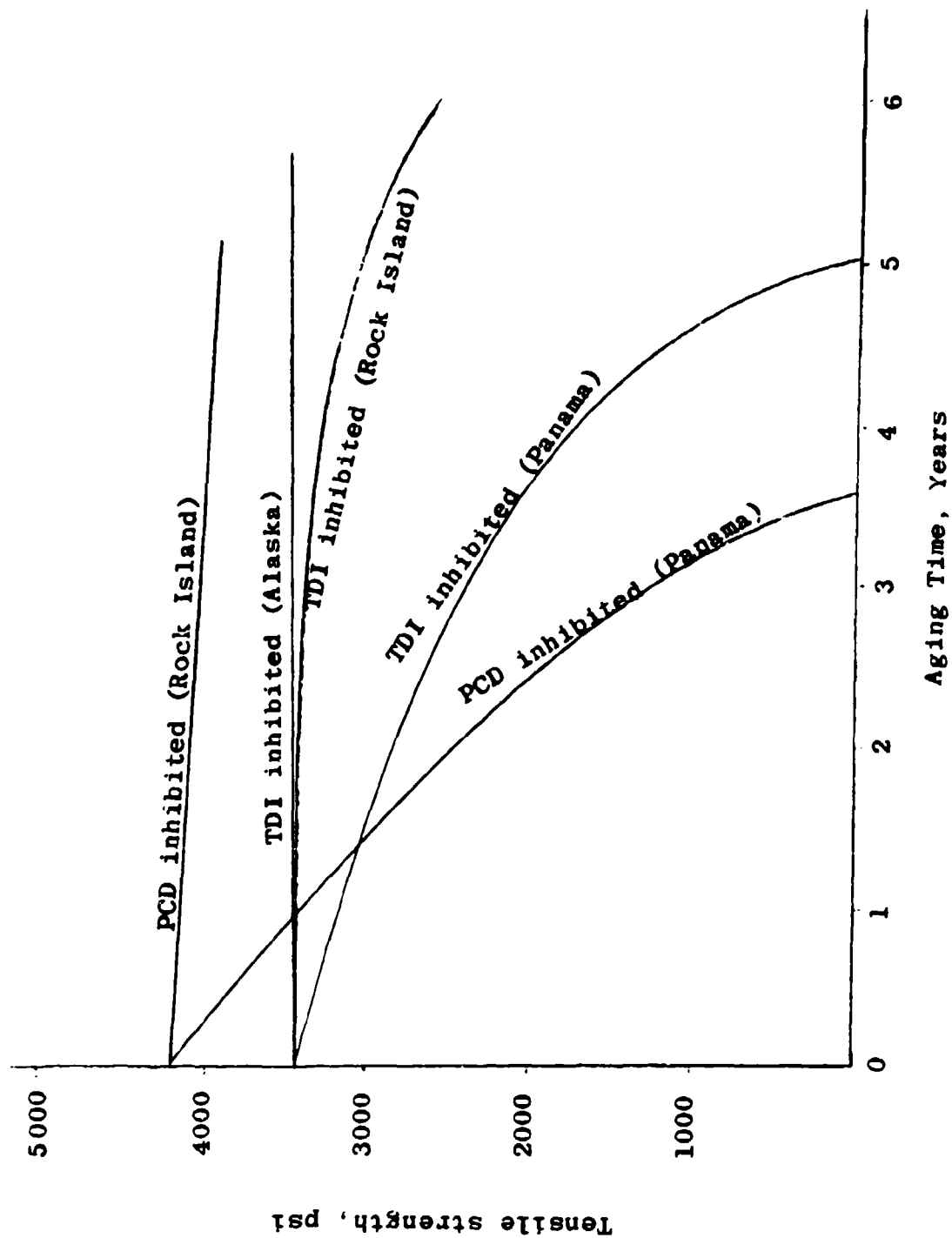


FIGURE 1
ENVIRONMENTAL AGING
OF HYDROLYSIS INHIBITED POLYESTER URETHANE VULCANIZATES



CROSS SECTION OF T142 TRACK PAD — SERVICE
TESTED 1171 MILES AT ABERDEEN PROVING GROUND



(UNHEATED)



(HEATED 3 DAYS
@ 212°F PRIOR TO TEST)

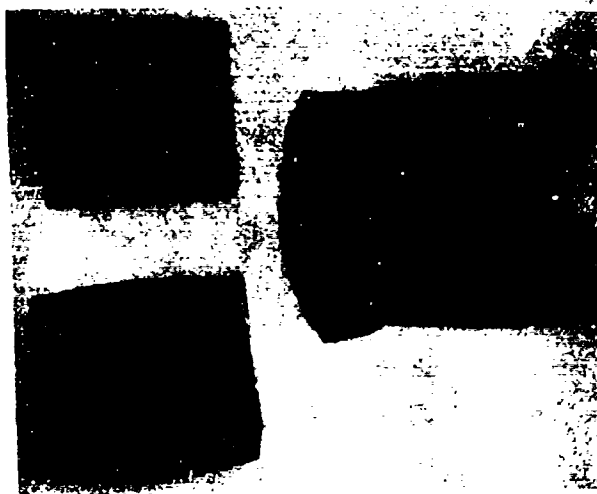
SPECIMENS TESTED ON FIRESTONE FLEXOMETER UNTIL TEMPERATURE
OF 350°F WAS REACHED (0.20" THROW - 600 LB. LOAD)

U.S. Army Weapons Command, Research and Engineering Directorate,
Science and Technology Laboratory 11-199-7764/AMC-69

FIGURE 2

Aged
2 hours @ 300°F

Aged
2 hours @ 350°F

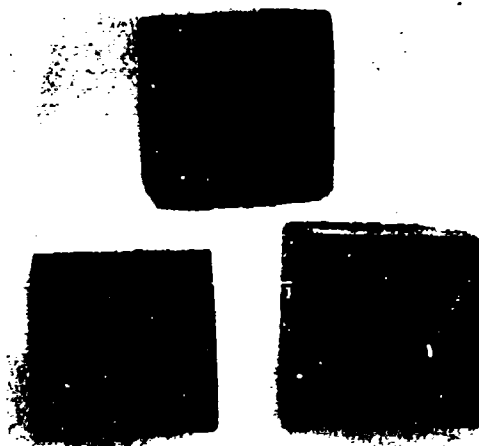


Aged
2 hours @ 400°F

Polyester Urethane (A) (Compound 1)

Aged
2 hours @ 300°F

Aged
2 hours @ 350°F



Aged
2 hours @ 400°F

SBR Control (Compound 12)

FIGURE 3

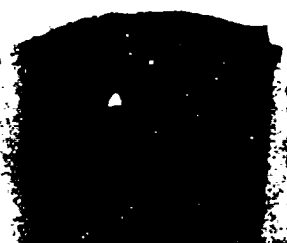
AIR OVEN-AGING OF SBR
AND POLYESTER URETHANE VULCANIZATES

Aged
2 hours @ 350°F



Conditioned
3 days @ 212°F
prior to aging
2 hours @ 350°F

Aged
2 hours @ 400°F



Conditioned
3 days @ 212°F
prior to aging
2 hours @ 350°F

Compound 1

Aged
2 hours @ 350°F



Conditioned
3 days @ 212°F
prior to aging
2 hours @ 350°F

Aged
2 hours @ 400°F

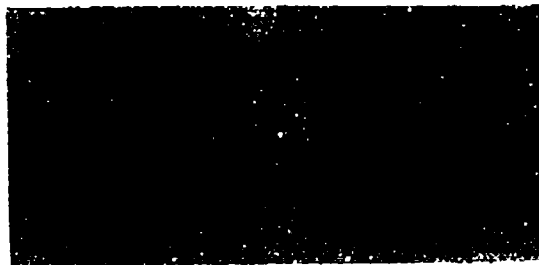


Conditioned
3 days @ 212°F
prior to aging
2 hours @ 350°F

Compound 2 - Contains PCD Inhibitor

FIGURE 4 AIR OVEN-AGING OF POSTCURED POLYESTER
URETHANE VULCANIZATES

Compound 3
(Contains no
CaO - control)



Compound 4
(Contains 5
parts/100 rhc
CaO)

Aged 2 Hours @ 350°F

Compound 3
(Contains no
CaO - control)



Compound 4
(Contains 5
parts/100 rhc
CaO)

Aged 2 Hours @ 400°F

FIGURE 5 AIR OVEN-AGING OF POLYESTER URETHANE
VULCANIZATES WITH AND WITHOUT CALCIUM OXIDE

TABLE IV

HYDROLYTIC STABILITY OF MILLABLE POLYESTER URETHANE VULCANIZATES
CONTAINING PCD WITH AND WITHOUT CALCIUM OXIDE

Physical Properties		Millable Polyester Urethane A Contains 4 parts/ 100 rhc PCD	Millable Polyester Urethane A Contains 4 parts/ 100 rhc PCD and 5 parts/100 rhc CaO
Original - Unaged			
Tensile, psi		4310	4530
300% Modulus, psi		1750	2490
Ultimate Elongation, %		540	450
Hardness, Shore A		71	73
Aged 30 days over H ₂ O @158°F			
Tensile, psi		3750	
300% Modulus, psi		1590	
Ultimate Elongation, %		540	
Hardness, Shore A		64	
			Specimens were too soft to test

Another disadvantage connected with the use of millable polyester urethanes is their high cost compared to SBR. Millable polyester urethane (A), for example, costs \$1.50 per pound compared with \$0.23 per pound for SBR 1500.

Compounding Studies

Compounding studies were carried out on numerous elastomers and blends of elastomers since issuance of the previous report⁶ on this subject. Track pads were prepared for service testing from the most promising compounds.

The curing systems and fillers evaluated in SBR 1500 are shown in Table I. Compounds cured with sulfur/N-cyclohexyl-2-benzothiazole sulfenamide (CBS) and dicumyl peroxide (DCP) have comparable physical properties at room temperature (compounds 5 and 6); but at 400°F, the tensile of the DCP-cured compound is somewhat better.

Comparisons of DCP, DCP-sulfur, and DCP-CBS (compounds 6-9) reveal that DCP-sulfur and DCP-CBS cured compounds have lower tensile strengths at room temperature and at 400°F than the compound cured with the use of DCP only. In addition, the compounds employing the DCP-sulfur cure exhibit lower modulus and higher elongation and tear resistance at both room temperature and 400°F. The DCP-CBS cured compound, on the other hand, exhibits higher modulus and hardness and lower elongation. An optimum cure resulted from a combination of DCP, sulfur and CBS (compound 10). Further studies with this cure (compounds 11, 13 and 14) revealed that the addition of fine particle size silica significantly improves the abrasion resistance and tear strength at room temperature and at 400°F (compound 14). Vulcanizates based on this cure had excellent air oven-aging resistance.

A maleimide-peroxide curing system (compound 15) is equal to the DCP-sulfur-CBS system for improved physical properties at ambient and elevated temperatures.

A lignin reinforced SBR compound (No. 16) supplied by the Defense Chemical Biological and Radiation Laboratories was evaluated. Tensile strength measured at 400°F was rather low.

A roll calendered coated fiberglass tire cord fabric was also evaluated in compound 12, but stress-strain properties could not be obtained because of the difficulty in molding ASTM test pads.

Comparisons of SBR/cis-polybutadiene blends (compounds 17-21) reveal the improvement in tensile strength at 400°F when a peroxide-sulfur-CBS curing system is used instead of a conventional sulfur-accelerator system. It is also evident that a fine particle size silica significantly improved the tear strength of these vulcanizates at both room temperature and 400°F. A compound suggested by a commercial manufacturer of SBR and polybutadiene (compound 22) was also evaluated. An antiozonant was added to provide O₃ resistance (compound 23).

Compounding studies were conducted with SBR/EPDM blends to develop ozone-resistant vulcanizates with physical properties suitable for track pad applications. One phase of this study revealed that excellent resistance to ozone could be obtained by use of an 85/15 blend of SBR 1500/ultra high Mooney EPDM (Mooney ML-4 @ 212°F over 200 (HM-EPDM)). The use of HM-EPDM rather than a conventional EPDM, e.g. 70 Mooney, resulted in superior stress-strain properties and abrasion resistance (compounds 24-27). It was desired to do more work with the HM-EPDM; however, this specialty polymer was no longer available.¹⁰ Meanwhile a comprehensive study was being conducted to define the extent of usefulness and limitations of ethylene-propylene copolymer and terpolymer rubbers as antiozonants for diene elastomers. This study¹¹ included conventional EPM and EPDM, HM-EPDM, and the newly introduced fast-curing EPDM elastomers (FC-EPDM). It was found that vulcanizates with excellent ozone resistance and other physical properties could be obtained by use of 70/30 blends of SBR 1500/FC-EPDM (compounds 28 and 29). It was also found that a vulcanizate (compound 30) prepared from a 85/15 blend of SBR 1500/140 Mooney EPDM (Mooney ML-4 @ 212°F - 140) had excellent physical properties and ozone resistance, but it has been learned that the 140 Mooney EPDM has also been withdrawn from the market.

Stereospecific SBR was investigated in blends with FC-EPDM (compounds 31 and 32). Original physical properties did not equal those of conventional SBR 1500/FC-EPDM blends although the tensile strength measured at 400°F was excellent. Tear resistance of SBR 1500/FC-EPDM and stereo SBR/FC-EPDM blends was poorer than that of vulcanizates prepared from SBR or FC-EPDM only.

SBR/cis-polybutadiene/EPDM blends (compounds 33 and 34) are also of interest because of their inherent ozone resistance. Although both compounds have excellent stress-strain properties, the SBR/cis-polybutadiene/HM-EPDM has very superior abrasion resistance. No attempt was made to fabricate track pads from this blend because the compound

is difficult to mix and has little or no building tack.

Formulations based on chlorobutyl only and chlorobutyl/FC-EPDM blends (compounds 35 and 36) were evaluated. Sufficient tensile strength could not be obtained with peroxide curable butyl compounds (37 and 38) to warrant further investigation.

Vulcanizates based on polyester urethane (B) and polyester urethane (C) stocks received fully compounded from the manufacturer were tested (compounds 39-41). These stocks were especially developed by the manufacturers for track pads. The vulcanizate prepared from the polyester urethane (C) stock had poor physical properties at elevated temperatures.

Glass fiber-filled polyester and polyether urethane vulcanizates furnished by the manufacturer had poor tensile strength at 250°F. The retention of tensile strength of the polyester pads was also poor after aging over water for 30 days at 158°F.

Service Tests of Experimental Track Pads

Since issuance of the previous report,⁶ experimental track pads were prepared for the following scheduled service tests:

<u>Test Site</u>	<u>Track Pad Type</u>	<u>Scheduled Starting Date</u>
1. General Motors Test Track at Milford, Michigan	T142	Spring 1967
2. FMC Corporation - San Jose, California	T130	Summer 1968
3. Aberdeen Proving Ground	T142	Summer 1969

The test scheduled for the GM test track at Milford was delayed over a period of months (because of carburetor trouble on the test vehicle and broken track) and was finally cancelled. The pads were placed in storage at ATAC where they are presently. The T142 track has been modified since the pads for the Milford test were prepared and will not accommodate the old style insert used in preparation of the pads for the Milford test.

The next scheduled test in early summer 1968, was a 6000-mile durability test to be performed on a M113A1 Vehicle S/N SJ-136 by the Ordnance Engineering Division of the FMC Corporation, San Jose, California. The M113A1

Vehicle uses T130 track pads, and fifty-five T130 pads prepared from various formulations (all but one of which were included in the Milford test) were sent to FMC. In addition, sixty-two T130 pads prepared from nine recipes featuring several polyester and polyether resins with several levels of fibrous glass reinforcement were injection-molded by the urethane manufacturer and also included. Service test results based on volume wear ratings of the 55 pads prepared by this Laboratory are given in Table VI. These results show that one compound performed slightly better than the commercial controls. This was a millable polyester urethane (A) compound containing 4 parts PCD hydrolysis inhibitor and 8 parts DCP curative. The compound that had demonstrated good wear resistance in previous tests (compound 1) demonstrated very poor wear resistance in this particular test, especially after 2000 or more miles. It is to be noted that service test results are given up to only 3000 miles, although the test was of a 6000-mile duration. This is due to the fact that many of the pads were removed prior to 4000 miles because of chunking and delamination or need for shoe change which resulted in an insufficient number of pads remaining to give meaningful results. As reported by FMC,¹² however, several isolated pads remained on the test vehicle for 5000 miles or more as reported below:

Compound (see Tables I and VI)	Mileage	Condition	Reason for Removal
Commercial control	5000	Good	Shoe changed
	6000	Fair	Some chunking and delamination at completed test
1	5500+	Fair	Some chunking and delamination at 5500 miles. lost during vehicle operation
13	5000	Good	Shoe changed
13	5500+	Good at 5000 miles	Shoe changed
44	6000	Fair	Shoe changed - some chunking
12	6000	Fair	Shoe changed - some chunking
12	6000	Fair	Some chunking, completed test

TABLE VI

RESULTS OF T130 TRACK PAD TEST
AT THE FMC CORPORATION, SAN JOSE, CALIFORNIA

Compound (See Table I)	Description	No. of Pads	Volume Wear Rating			
			500 miles	1000 miles	2000 miles	3000 miles
2	Millable Polyester Urethane (A) (contains PCD)	5	116	114	107	102
-	Commercial Control Pads	5	100	100	100	100
13	SBR 1500-Sulfur/CBS/DCP cure	5	97	97	91	93
12	SBR 1500-Science and Tech- nology Lab. Control Compound	5	103	96	90	91
45	SBR 1500-Sulfur/CBS/DCP cure Fine particle silica (B) added	5	89	91	90	91
25	85/15 SBR 1500/HM-EPDM	5	91	89	86	87
21	75/25 SBR 1500/cis Poly- butadiene (A)	5	77	80	80	83
1	Millable Polyester Urethane (A) (Four different bonding systems)	20	95	90	72	70
44	100/30 Stereospecific SBR (C)/HM-EPDM	5	69	65	62	35

The injection molded glass reinforced polyurethane pads performed poorly in the service test. After only 100 miles, the pads were worn flush with the shoe grousers, and had to be removed from test after 151 miles of operation. It was reported by FMC¹³ that the pads also lacked adequate traction.

In the summer of 1968, twelve T142 pads prepared from millable polyester urethane (A) (compound 1) were tested for 1171 miles, the first 100 miles at ATAC and the remainder at APG. After 1171 miles, the pads had a volume wear rating of 145. It was in this test that the severe internal gassing due to high-heat buildup was noticed.

This Laboratory was afforded the opportunity to place additional T142 pads at APG in service tests scheduled for the summer of 1969. Included were millable polyester urethane pads prepared from stock received fully compounded from two different commercial manufacturers (millable polyester urethanes (B) and (C)). The results of these tests are given in Table VII. The internal gassing and porosity noticed in the millable polyester (A) pads in the previous test was again noted. It was found that the addition of calcium oxide eliminated the gassing and porosity, but pads containing this additive (compound 4) had poor wear resistance. Test pads prepared from millable polyester urethanes (B) and (C) received fully compounded from the manufacturers also exhibited poor wear resistance.

In a previous report on this subject,⁶ it was stated that results up to that time had indicated that poor wear ratings had been associated with the use of PCD in millable polyester urethanes. The volume wear ratings to date of track pads with and without hydrolysis inhibitors (PCD or TDI) are given in Table VIII. These results reveal a large spread in wear ratings no matter which hydrolysis inhibitor is used. However, compound No. 1 containing no inhibitor shows a better wear rating than those with inhibitors.

A summary of volume wear-ratings (best to worst) of all compounds service-tested in this program, since the issuance of the latest report⁶ is given in Table IX. Only the millable polyester urethane (A) pads gave volume-wear ratings greater than those of the commercial control pads.

TABLE VII

RESULTS OF T142 TRACK PAD TEST AT APG

Test A

Compound	Description	No. of Pads	Volume Wear Rating		
			791 Miles	995 Miles	1035 Miles
-	Commercial Control Pads	17	100	100	100
1	Milable Polyester Urethane (A)	8	117 ^a	-	-
46	Milable Polyester Urethane (A) (Contains TDI)	8	-	-	121
47	Milable Polyester Urethane (A) (Contains PCD)	8	-	-	117 ^b
48	70/30 SBR 1500/FC-EPDM(C)	5	-	-	74 ^c
49	70/30 Stereospecific SBR(B)/ FC-EPDM(D)	5	-	-	-

All pads removed from test after 150 miles (tearing and chunking - worn down to grouser)

Test B

Compound	Description	No. of Pads	Volume Wear Rating	
			686 Miles	
-	Commercial Control Pads	15	100	
39	Milable Polyester Urethane (B)	9	37 ^d	
40	Milable Polyester Urethane (B)	9	57 ^d	
41	Milable Polyester Urethane (C)	6	82	
3	Milable Polyester Urethane (A) (Contains PCD)	6	108 ^e	
50	Milable Polyester Urethane (A) (Pads postcured 70 hrs @ 212°F)	6	109 ^e	
4	Milable Polyester Urethane (A) (Contains PCD and CaO)	6	79	

^aRemoved after 791 miles - "blowout" type failures and porosity
^bTwo pads removed after 791 miles and two removed after 995 miles due to delamination and porosity - four pads remained after 1035 miles

^cTwo pads removed after 791 miles due to delamination
^dCutting and chunking on pad surface
^ePads showed evidence of delamination and some blowout failures were evident

TABLE VIII

VOLUME-WEAR RATINGS OF MILLABLE POLYESTER URETHANE
TRACK PADS CONTAINING HYDROLYSIS INHIBITORS

Compound	Elastomer	Inhibitor	Track Pad Type	No. of Pads Tested	Test Site*	Total Miles (all tests)	Volume Wear Rating
1	Millable Polyester Urethane (A)	-	T130 & T142	195	1, 2, 3, 4	13,281	141
51	Millable Polyester Urethane (D)	-	T130	49	2, 4	1,100	123
52	Millable Polyester Urethane (A)	TDI	T130	7	1	500	122
46	Millable Polyester Urethane (A)	TDI	T142	8	2	1,035	121
47	Millable Polyester Urethane (A)	PCD	T142	8	2	1,035	117
53	Millable Polyester Urethane (A)	TDI	T130	7	1	500	116
3	Millable Polyester Urethane (A)	PCD	T142	6	2	686	108
54	Millable Polyester Urethane (D)	-	T130	10	3	600	107
55	Millable Polyester Urethane (A)	-	T130	7	1	500	104
56	Millable Polyester Urethane (A)	TDI	T130	7	1	500	104
2	Millable Polyester Urethane (A)	PCD	T130	5	3	3,000	102
-	Commercial Control	-	T130 & T142	-	1, 2, 3, 4	-	100
57	Millable Polyester Urethane (A)	TDI	T130	7	1	500	81
58	Millable Polyester Urethane (C)	PCD	T142	40	2	930	81
59	Millable Polyester Urethane (D)	PCD	T130	42	3, 4	2,600	78
40	Millable Polyester Urethane (B)	PCD	T142	9	2	686	57
39	Millable Polyester Urethane (B)	PCD	T142	9	2	686	37

*Test Sites: 1 - ATAC
2 - APG
3 - FMC
4 - Yuma

TABLE IX

VOLUME-WEAR RATING SUMMARY

Compound	Elastomer	Track Pad Type	No. of Pads Tested	Test Site	Total Miles (all Tests)	Volume Wear Rating
46	Milable Polyester Urethane (A) (Contains TDI)	T142	8	APG	1035	121
47	Milable Polyester Urethane (A) (Contains PCD)	T142	8	APG	1035	117
1	Milable Polyester Urethane (A)	T130 & T142	40	APG & FMC	4962	111
50	Milable Polyester Urethane (A) (Postcured 70 hrs @ 212°F)		6		686	109
3	Milable Polyester Urethane (A) (Contains PCD)	T142	6	APG	686	108
2	Milable Polyester Urethane (A) (Contains PCD)	T130	5	FMC	3000	102
-	Commercial Control	T130 & T142	37+	APG & FMC	5000+	100
13	SBR 1500-Sulfur/CBS/DCP cure		5		3000	93
45	SBR 1500-Sulfur/CBS/DCP cure - Fine particle silica added		5		3000	91
12	SBR 1500-Science and Technology Lab. Control	T130	5	FMC	3000	91
25	85/15 SBR 1500/HM-EPDM	T130	5	FMC	3000	87
21	75/25 SBR 1500/cis Poly- butadiene (A)	T130	5	FMC	3000	83
41	Milable Polyester Urethane (C)	T142	6	APG	686	82
4	Milable Polyester Urethane (A) (Contains PCD plus CaO)	T142	6	APG	686	79
48	70/30 SBR 1500/FC-EPDM(C)	T142	5	APG	1035	74
40	Milable Polyester Urethane (B)	T142	9	APG	686	57
39	Milable Polyester Urethane (B)	T142	9	APG	686	37
44	100/30 Stereospecific SBR(C)/ HM-EPDM	T130	5	FMC	3000	35
49	70/30 Stereospecific SBR(B)/ FC-EPDM(D)	T142	5	APG	1035	Worn to grouser after 150 miles

Correlation of Laboratory Tests with Service Performance

Since obvious advantages would exist if it were possible to forecast the wear characteristics of a vulcanizate without actually conducting a costly and time consuming service test, attempts were made to correlate service performance with an accelerated static or dynamic laboratory test. It has been previously stated⁶ that, in the case of the urethanes, good service durability was associated with good stress-strain properties at elevated temperatures. This appears to hold true in most cases for the millable urethanes but not for the other elastomers, as shown in Table X.

Attempts were made to correlate service performance with resistance to crack growth as measured on the DeMattia tester (ASTM D813-59). These results, given in Table XI, indicate that the crack growth test may predict how the millable polyester urethane vulcanizates will wear, but it does not appear to be accurate in predicting how the elastomers will perform in service when compared with one another. Some correlation does appear to exist, however, in cases where compounds exhibit extremely good (crack growth of 3/32 or less) or extremely poor (cracks across in less than 1500 cycles or so) crack growth resistance on the DeMattia. Specimens of millable polyester urethane A (compound 1) showed a crack growth of only 2/32 after 50,000 cycles, and the average volume-wear rating for all service tests on this compound is 141. On the other hand, specimens based on carboxylic elastomer (compound 64) cracked completely across in less than 600 cycles, and the volume rating is only 46. The difference in crack growth rate for the two compounds is very evident in Figure 7, which shows the specimens after 50,000 cycles in comparison with the Science and Technology Laboratory SBR control compound. Additional test results will have to be obtained in future service tests to verify this correlation.

In other attempts to obtain correlation, tear resistance (ASTM D624-54, Die C), heat buildup (Firestone Flexometer) and compression modulus (ASTM D575-67, Method A) were investigated. These results are shown in Table XII. With regard to the millable polyester urethanes, some correlation appears to exist between service performance and the properties measured. A good volume-wear rating (one greater than 100) appears to be directly proportional to good tear strength and inversely proportional to low heat buildup and high compression modulus.

TABLE X

SERVICE PERFORMANCE VS. STRESS-STRAIN PROPERTIES AT 400°F

Material	Tensile Strength, psi		Ultimate Elongation, %		Volume Wear Rating
	Ambient	400°F	Ambient	400°F	
70/30 Stereospecific SBR(B)/FC-EPDM(D)	4520	630	370	141	2290
75/25 SBR 1500/cis-polybutadiene (A)	4420	370	300	37	2880
SBR 1500 (Sulfur/CBS/DCP cure - Fine particle silica added)	4420	370	105	37	3560
70 Mooney EPDM	4420	370	300	37	3450
70/30 SBR 1500/FC-EPDM(C)	4420	370	300	37	3080
85/15 SBR 1500/HM-EPDM	4420	370	300	37	3410
SBR 1500 (Sulfur/CBS/DCP cure)	4420	370	300	37	3890
Carboxylic Elastomer	4420	370	300	37	4370
Millable Polyether Urethane	4420	370	300	37	5510
Millable Polyester Urethane (A) (Contains TDI)	4420	370	300	37	5700
Millable Polyester Urethane (A) (Contains PCD)	4420	370	300	37	4530
Millable Polyester Urethane (A) (Contains TDI)	4420	370	300	37	6490
Millable Polyester Urethane (D)	4420	370	300	37	5590
Millable Polyester Urethane (C)	4420	370	300	37	3650
Millable Polyester Urethane (B)	4420	370	300	37	4420
Millable Polyester Urethane (A)	4420	370	300	37	4520

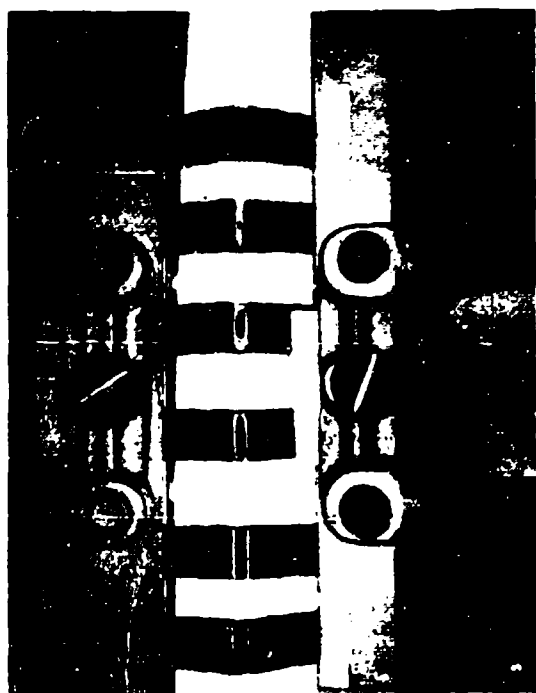
*Blisters at 400°F

**Worn to grouser after 150 miles

TABLE XI

SERVICE PERFORMANCE VS. CRACK GROWTH (DeMATtIA)

Compound	Elastomer	Crack Growth DeMatia Tester 50,000 cycles	Volume Wear Rating
1	Millable Polyester Urethane (A)	2	141
50	Millable Polyester Urethane (A)	2	109
3	Millable Polyester Urethane (A)	2	108
2	Millable Polyester Urethane (A)	5	102
4	Millable Polyester Urethane (A)	19	79
41	Millable Polyester Urethane (C)	cracked across <3000 cycles	82
40	Millable Polyester Urethane (B)	cracked across <1500 cycles	57
39	Millable Polyester Urethane (B)	cracked across <50 cycles	37
63	75/25 SBR 1500/cis-Polybuta- diene (A)	25 - 27	126
12	SBR 1500 - Science and Technology Lab. Control Compound	26 - 28	107
62	70 Mooney EPDM	17 - 18	97
13	SBR 1500-Sulfur/CBS/DCP cure	18 - 21	93
45	SBR 1500-Sulfur/CBS/DCP cure Fine particle silica (B) added	19 - 21	91
25	85/15 SBR 1500/HM-EPDM	8 - 12	87
21	75/25 SBR 1500/cis-Polybuta- diene (A)	15 - 17	83
60	Isoprene	15 - 20	76
61	Polyoxypropylene	19 - 25 at 30,000 cycles cracked across 40,000 cycles	55



Left - Carboxylic
(Compound 64)

Middle - SBR 1500
(Compound 12)

Right - Millable Polyester
Urethane A
(Compound 1)

FIGURE 7
CRACK GROWTH OF CARBOXYLIC, SBR 1500 AND MILLABLE
POLYESTER URETHANE SPECIMENS AFTER 50,000 CYCLES
OF FLEXING ON THE DEMATTIA TESTER

TABLE XII

SERVICE PERFORMANCE VS. TEAR RESISTANCE, HEAT BUILDUP AND COMPRESSION MODULUS

Compound	Elastomer	Tear, pl, Die C	Firestone Flexometer, Time to go from 100 - 200°F, minutes	Compression		Volume Wear Rating
				psi	Modulus,	
1	Millable Polyester Urethane (A)	241	3.9	245		141
50	Millable Polyester Urethane (A)	240	5.7	379		109
3	Millable Polyester Urethane (A)	225	5.6	359		108
2	Millable Polyester Urethane (A)	262	11.0	340		102
41	Millable Polyester Urethane (C)	173	11.3	420		82
4	Millable Polyester Urethane (A)	205	11.5	412		79
40	Millable Polyester Urethane (B)	179	33.4	800		57
39	Millable Polyester Urethane (B)	131	+60	630		37
12	SBR 1500 - Science and Technology Laboratory Control Compound	176	23.0	330		107
13	SBR 1500-Sulfur/CBS/DCP cure	175	10.1	320		93
45	SBR 1500-Sulfur/CBS/DCP cure Fine particle silica added	186	9.3	305		91
25	85/15 SBR 1500/HM-EPDM	227	8.6	420		87
21	75/25 SBR 1500/cis-Polybutadiene (A)	227	9.9	330		83
44	100/30 Stereospecific SBR(C)/HM-EPDM	188	33.7	295		35

Again, however, additional data will have to be obtained to verify these findings. At the present time, no evidence of correlation exists between service performance and the properties measured for the other elastomers or blends of elastomers.

Polyester Urethane Rubber-to-Metal Bond Studies

A four-year study has been concluded which was designed to determine the effect of shelf-aging at ambient temperature and storage at 100 percent relative humidity on the 90 degree peel strength of millable polyester urethane A and D vulcanizates bonded to 1020 steel with two different bonding systems (Table XIII). These millable gums compounded with a polycarbodiimide hydrolysis inhibitor (PCD) and bonded with Bonding System 2 were the only formulations which exhibited no appreciable loss in 90-degree peel strength after a 2-year period under either environmental condition. The PCD inhibitor also appeared to improve the stability of Bonding System 1 to some extent. The 4-year aging results reveal that (1) shelf-aged specimens bonded with System 2 exhibit excellent bond retention whereas specimens exposed to 100 percent R.H. exhibit more than a 50 percent loss from the original bond strength values, (2) 90-degree peel strength values for Bonding System 1 are significantly lower than those for Bonding System 2, (3) the lower rubber-to-metal bond strength values for all specimens exposed to the 100 percent R.H. atmosphere probably can be attributed to the poor hydrolytic stability of the polyester urethane elastomers rather than to the instability of the bonding system employed, and (4) the PCD-inhibited gum A bonded with System 2 appears to be adequate for tank track pad application as far as the environmental stability of the bond is concerned.

It was postulated that high temperature bond retention at tank track pad operating temperature (250°F) was another important criterion necessary for an acceptable rubber-to-metal bonding system. Accordingly, 90-degree peel strengths were determined on candidate urethane bond systems at 250°F and at ambient temperature and are shown in Table XIV. The importance of high-temperature bond strength becomes quite evident when one examines adhesive service performance and laboratory test data at elevated temperature. For example, poor bond strength retention of bond systems 1 and 3 correlates with numerous rubber-to-metal bond separations that occurred during early service tests. Correspondingly, good bond strength at 250°F for Bonding Systems 4, 5 and 6 further substantiate

TABLE XIII

RUBBER-TO-METAL BOND STRENGTH AFTER 4-YEAR AGING

Compounding Ingredients	Formulations							
	65	66	66	66	67	68	67	68
Millable Polyester Urethane D	100	100	100	100				
Millable Polyester Urethane A					100	100	100	100
ISAF Carbon Black B	30	30	30	30				
SAF Carbon Black A					40	40	40	40
Stearic Acid	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Dicumyl Peroxide (40% active)	8	8	8	8	8	8	8	8
Polycarbodiimide (PCD)		4	4	4		4		4
Bonding System Used***	1	1	2	2	1	1	2	2

		90-Degree Peel Strengths, lb/in.									
1 Year	Unaged Specimens	50	135	150	130	95	175	160			
	Shelf	50	160	170	100	115	220	170			
2 Years	100% R. H.	*	100	135	80	50	85	140			
	Shelf	55	135	180	100	100	225	165			
4 Years	100% R. H.	**	90	140	60	40	65	160			
	Shelf	15	70	170	60	105	--	160			
	100% R. H.	**	45	65	5**	50	10**	95			

*Hand Stripped

**Specimen Hydrolyzed

***Bonding Systems Identified on Code Sheet

TABLE XIV

HIGH TEMPERATURE BOND STRENGTH*

Bonding System**	90-Degree Peel Strength at Ambient Temperature, lb/in.	90-Degree Peel Strength at 250°F, lb/in.
1	120	45
3	150	25
4	150	110
5	170	110
6	195	125

*Compound 1 used for this evaluation - Millable Polyester Urethane (A) 100,
SAF Carbon Black A 40, Dicumyl Peroxide 7, Stearic Acid 0.2

**Bonding systems identified on code sheet

this claim in that no polyester urethane pads separated from the metal inserts because of bond failure during the latest FMC and Aberdeen service tests when these systems were used.

Rubber-to-metal bond strength data obtained from T130 polyester urethane track pads that were bonded with System 4 and subjected to outdoor exposure for 1 year at Rock Island, Illinois, and at Panama Canal Zone are contained in Table XV. The bond strengths determined on the aged pads indicate that (1) the pads fabricated from the PCD-inhibited elastomer (compound 2) show little or no change in 90-degree peel strength after aging and (2) the bond strengths of the uninhibited pads (compound 1) dropped significantly.

TABLE XV

RUBBER-TO-METAL BOND STRENGTHS OF POLYESTER TRACK PADS
AFTER 1 YEAR OF OUTDOOR AGING AT
ROCK ISLAND AND AT PANAMA CANAL ZONE

Recipe	Time and Location of Exposure	90-Degree Peel Strength* (lb/in.)	Type of Failure, Percent	
			R**	RC***
Compound 1 (Uninhibited)	Unaged Pad	190	100	0
	1 Yr, Rock Island	175	90	10
	1 Yr, Open Sun Panama	75	10	90
	1 Yr, Rain Forest Panama	160	30	70
Compound 2 (Inhibited)	Unaged Pad	190	100	0
	1 Yr, Rock Island	175	65	35
	1 Yr, Open Sun Panama	230	85	15
	1 Yr, Rain Forest Panama	220	100	0

*Bonding System 4 used.

**R indicates failure in the rubber.

***RC indicates failure in the rubber-cover cement interface.

CONCLUSIONS

Track pads fabricated from certain millable polyester urethanes continue to demonstrate the best resistance to wear when compared with commercial SBR pads. The high cost and the poor hydrolytic stability of the polyester urethanes, even when hydrolysis inhibitors are incorporated, may preclude their use in this application.

The addition of small amounts of calcium oxide eliminates the porosity caused by heat buildup in millable polyester urethane track pads service tested at high speeds, but has an adverse effect on the hydrolytic stability and wear resistance of vulcanizates inhibited with PCD.

A satisfactory rubber-to-metal bonding system for millable polyester urethanes has been found.

RECOMMENDATIONS

A concentrated effort should be made to have a service test performed on the T142 pads which were prepared for the service test scheduled for the General Motors test track at Milford, Michigan. It is believed that much valuable data could be obtained on these pads even though they are now two to three years old.

Efforts should continue in the search for improved track pads fabricated from elastomers other than the millable polyester urethanes.

The search should continue for a more effective hydrolysis inhibitor for the millable polyester urethanes.

ACKNOWLEDGEMENT

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Supplied to PEC by Rock Island Arsenal during
early 1968.
13. Letter from FMC to ATAC, dated 10 February 1969,
Subject: Test of Glass Reinforced Estane Poly-
urethane, Injection Moulded Track Pads.

CODE SHEET

Description or Chemical Name	Trade Name	Supplier
Millable Polyester Urethane (A)	Genthan SE	General Tire & Rubber Co.
Millable Polyester Urethane (B)	Vibrathane 5004	Uniroyal, Inc.
Millable Polyester Urethane (C)	Elastothane ZR625	Thiokol Chem. Corp.
Millable Polyester Urethane (D)	Genthan S	General Tire & Rubber Co.
Millable Polyether Urethane	Adiprene C	E. I. DuPont de Nemours & Co.
SBR 1500	Philprene 1500	Phillips Petroleum Co.
Oil-Black Masterbatch SBR	Philprene 1609	Phillips Petroleum Co.
Stereospecific SBR (A)	Stereon 700	Firestone Tire & Rubber Co.
Stereospecific SBR (B)	Stereon 720	Firestone Tire & Rubber Co.
Stereospecific SBR (C)	Duradene	Firestone Tire & Rubber Co.
Cis Polybutadiene (A)	Diene	Firestone Tire & Rubber Co.
Cis Polybutadiene (B)	Cis 4-1350	Phillips Petroleum Co.
High Mooney EPDM	Royalene F65-3-9H	Uniroyal, Inc.
70 Mooney EPDM	Nordel 1070	E. I. DuPont de Nemours & Co.
140 Mooney EPDM	Royalene 200	Uniroyal, Inc.
Fast Curing EPDM (A)	EP syn 55	Copolymer Rubber & Chemical Corp.
Fast Curing EPDM (B)	Vistalon 6505	Enjay Chemical Co.
Fast Curing EPDM (C)	Nordel 1470	E. I. DuPont de Nemours & Co.
Fast Curing EPDM (D)	Nordel 1470	E. I. DuPont de Nemours & Co.
Chlorinated Butyl	HT-1066	Enjay Chemical Co.
Peroxide Curable Butyl	Polycar V3301	Polymer Corp. Limited
Chlorosulfonated Polyethylene	Hypalon 40	E. I. DuPont de Nemours & Co.
Pol: -vpropylene	Dynagen XP-139	General Tire & Rubber Co.
Carboxylic Elastomer	Hycar 1072	B. F. Goodrich Co.
SAF Carbon Black (A)	Statex 160	Columbian Carbon
SAF Carbon Black (B)	Philblack E	Phillips Petroleum Co.
SAF Carbon Black (C)	Neotex 150	Columbian Carbon
ISAF Carbon Black (A)	Neotex 130	Columbian Carbon
ISAF Carbon Black (B)	Statex 125	Columbian Carbon
HAF Carbon Black	Philblack O	Phillips Petroleum Co.
SPF Carbon Black	United U65	United Carbon Co.
EPC Carbon Black	Kosmobile 77	United Carbon Co.
Fine particle size silica (A)	Cab-O-Sil MS-7	Cabot Corp.
Fine particle size silica (B)	Cab-O-Sil H5	Cabot Corp.
N-cyclohexyl-2-benzothiazole-sulfenamide	Santocure	Monsanto Co.
N-t-butyl-2-benzothiazole-sulfenamide	Santocure NS	Monsanto Co.
Tetramethyl Thiuram Disulfide	Methyl Tuads	R. T. Vanderbilt Co.
Benzothiazyl Disulfide	Altax	R. T. Vanderbilt Co.
Dipentamethylene Thiuram tetrasulfide	Tetrone A	E. I. DuPont de Nemours & Co.
Tetramethyl Thiuram Monosulfide	Thionex	E. I. DuPont de Nemours & Co.

CODE SHEET (continued)

Description or Chemical Name	Trade Name	Supplier
Zinc salt of 2-mercapto-benzo-thiazole	ZMBT	American Cyanamid
Dicumyl peroxide (40% active)	Di Cup 40C	Hercules, Inc.
Dicumyl peroxide (recrystallized)	Di Cup R	Hercules, Inc.
Trimethyl dihydroquinoline	Agerite Resin D	R. T. Vanderbilt Co.
Phenyl-beta-naphthylamine	Neozone D	E. I. DuPont de Nemours & Co.
Amine Antioxidant Mixture	Thermoflex A	E. I. DuPont de Nemours & Co.
N,N'-diphenyl-p-phenylenediamine	JZF	E. I. DuPont de Nemours & Co.
2,2'-methylenebis(4-methyl-6-t-butyl-phenol)	Antioxidant 2246	American Cyanamid Co.
N-phenyl-N'-cyclohexyl-p-phenylenediamine	Antioxidant 4010	Bayer (Germany)
N,N'-dioctyl-p-phenylenediamine	U.O.P. 88	Universal Oil Products Co.
6-ethoxy-1,2-dihydro-2,2,4-trimethyl quinoline	Santoflex AW	Monsanto Co.
Wax	Heliозone	E. I. DuPont de Nemours & Co.
Ultra high molecular weight polyethylene	H1 Fax 1900	Hercules, Inc.
Fiberglass tire cord	G150 10/0 1.5S T063, 16 epi, 22" wide, coated with OCF 2010	Owens Corning, Fiberglas Corp.
Tl30 injection molded urethane pads with various fibrous glass reinforcement	Estane (urethane)	B. F. Goodrich Co.
Polycarbodiimide	PCD	Naftone, Inc.
Diisocyanate (TDI)	Multrathane El64	Mobay
Bonding System #1	Thixon P4/P3	Whittaker Corp.
Bonding System #2	Thixon XD 9777/ Thixon XAB936	Whittaker Corp.
Bonding System #3	Thixon P4/Thixon XAB936	Whittaker Corp.
Bonding System #4	Thixon P4/Thixon XAB936/Mondur TM	Whittaker Corp.
Bonding System #5	Chemlock 205/ Hughson TS-701-45	Hughson Chemical Co.
Bonding System #6	Chemlock 205/ Hughson TS-701-46	Hughson Chemical Co.

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