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**COMPOUNDING ELASTOMERS FOR USE IN
ARMAMENT APPLICATIONS**

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TECHNICAL REPORT



RESEARCH DIRECTORATE

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A commercial masterbatch of a phosphonitrilic polymer proved to be much easier to mill-mix than the gum elastomer itself. Vanfre AP-2 processing aid improved the mold flow of a nitrile-based compound developed for use in the fabrication of oil seals. Antox N was found to be a suitable antioxidant to replace Neozone D that has been removed from the market. The shape factor of 175mm neoprene rubber obturator pads was reduced by the placement of blind holes in one pad surface, hence the low-temperature compressibility was improved. Satisfactory		

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compounds, based on polymer blends, were developed for potential use in the fabrication of obturator pads, barrier bags for the 152mm combustible-cased round, and seals for use in flame-resistant hydraulic fluid.

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OBJECTIVE

The object of this work was to develop improved rubber compounds specifically designed for potential use in the fabrication of a variety of armament components. The improvements were to be achieved by the most recent techniques of rubber compounding, involving new polymers, new rubber additives, and polymer blends.

BACKGROUND

The development of improved rubber compounds for use in the fabrication of armament components is necessary because of the increasing demands created by the severe operating conditions of modern weapons and munitions. Although the rubber components in use today are, for the large part, high quality products, deficiencies in their performance exist. Thus, the state of the art of rubber technology should be advanced to the extent that the deficiencies in currently used materials can be remedied and that new, improved materials will be made available for use in future designs.

APPROACH

Phosphonitrilic Polymers

Earlier work¹ on phosphonitrilic (phosphazene) polymers showed that vulcanizates of these elastomers had excellent low-temperature properties and were resistant to a variety of fuels and oils. These properties made the polymers likely choices for oil seal applications in recoil mechanisms or in the M140 gun mount where seal performance at low temperatures needs improvement without loss of resistance to oil. These polymers, however, have proved to be difficult to process on a two-roll mill and are unreceptive to the incorporation of reinforcing fillers. The need for filler reinforcement is evident from the low tensile strengths (approx. 1000 psi) of the vulcanizates. The approach taken in the current study involved work with a newly commercialized phosphonitrilic masterbatch which was reportedly easier to process than the earlier polymers and to attempt to improve tensile strength by the addition of reinforcing silica fillers.

Oil Seals

A rubber compound for use in the fabrication of oil seals was devel-

¹ Rock Island Arsenal Technical Report R-TR-75-007, "Compounding Studies on Polyphosphazene Polymers," February 1975.

oped and reported last year.² The compound compared favorably in physical properties to the best commercially available seal compound and in some respects was an improved material. This earlier work was prompted by the fact that commercial seals were becoming extremely expensive and required long lead times for their procurement. Rock Island Arsenal planned to develop an in-house capability at the Arsenal Operations Directorate for producing seals for the M140 gun mount. The new compound, when tried in an injection mold, failed to flow properly through the mold sprues. The approach taken during FY76 to correct this condition involved the evaluation of a newly marketed processing aid to determine whether this material would improve the flow characteristics of the rubber without detracting from other properties.

Compound Updating

Since its inception in 1946, the Rubber Laboratory of the Research Directorate has developed approximately 170 rubber compounds for use by the Operations Directorate at Rock Island Arsenal in the fabrication of pilot lot quantities of weapon components. It is a continuing task to monitor the state of the art of rubber compounding to be able to update these compounds to take advantage of new, less expensive, more efficient rubber ingredients. The need for updating often results from the removal from the market of one or more of the ingredients. Such was the case during FY76 when the manufacturer of the antioxidant Neozone D (N-phenyl-beta-naphthylamine) terminated the production of this suspected carcinogen. Because Neozone D had been widely used in SBR and in neoprene-based production compounds, the evaluation of a replacement antioxidant was undertaken in typical polymers of these two classes.

Obturator Pads

Reports from the field have indicated that the standard obturator pad for 175mm and 8-inch cannon has not been performing satisfactorily. The life of these pads has ranged from 30 to 349 rounds (zone 9 charge, 1 round every 2 minutes), a rather low service life. This pad, developed by Watervliet Arsenal, is made of asbestos-filled silicone rubber that is contained in a wire mesh basket; this construction does not lend itself to rapid production and, thus, is very expensive. The success achieved by the Research Directorate several years ago in the development of the now standard neoprene rubber pad for 155mm cannon foreshadowed the current investigation of the feasibility of using the same rubber compound in the larger pad. Accordingly, neoprene pads were molded in the 175mm or 8-inch configuration and arrangements were made to have the pads

² Rock Island Arsenal Technical Report R-TR-76 - 035, "Development and Evaluation of Elastomers for Improved Seals and Obturators," October 1975.

tested under actual firing conditions. From earlier work, the belief was that the 175mm pad would not function at temperatures colder than -25 F, even though the 155mm pad made of the same rubber is functional below -50 F. Thus, means were devised to improve the low-temperature performance of the pad.

Polymer Blends

Today's conditions of economic stresses and energy shortages are largely responsible for the widespread industrial and governmental investigations on the development of polymer blends. The economic situation has virtually put a halt to the synthesis of new polymers, an endeavor that entails the expenditure of large amounts of time and money with payoffs being long range in nature. Thus, the current trend in the rubber producing industry is to exploit existing elastomers and elastomer blends. Energy shortages have stimulated work on blends as a means of reducing the production of elastomers that require large energy expenditures. Neoprene rubber, for example, is undesirable to produce today because of the high electrical demands required to produce chlorine. The work on polymer blends reported herein was stimulated by these two conditions and also by a strictly technological reason, namely, that blends often possess properties or combinations of properties unattainable in a single polymer.

The work on blends was directed toward three specific weapon components: barrier bags for combustible-cased ammunition, oil seals, and obturator pads. For the first and second of these items, blends were sought to improve certain properties of the single elastomers now used. For the third item, blends were developed in an attempt to replace the neoprene currently used.

RESULTS AND DISCUSSION

Phosphonitrilic Polymers

The formulations and physical properties of the vulcanizates are listed in Tables 1 and 2, respectively. The PNF200 masterbatch was much easier to work with than was the polymer itself. However, incorporation of 10 pphr of silica filler became difficult and addition of a higher level would appear to be rather cumbersome. The Hi Sil 233 did not impart higher tensile strength, but did raise the modulus and increased the hardness by approximately 10 points for each 5 pphr of filler. Other physical properties were not significantly affected by the addition of the filler.

Oil Seals

For improvement of the mold flow of the rubber compound to be used

in the production of M140 gun mount seals, a new processing aid was evaluated. The compounding ingredients are given in Table 3 and the physical properties of the vulcanizates are shown in Table 4. The processing aid, Vanfre AP-2, did not affect the properties measured, even when used at 3 pphr. All compounds were molded in the laboratory in an 8-inch-long cylindrical mold that produced rubber cylinders with a cross section of 0.125 inch. Qualitatively, the compounds containing Vanfre AP-2 flowed better than the control compound. This was determined by the use of equivalent quantities of rubber under the same amount of pressure. Compounds containing Vanfre AP-2 were found to flow farther than the compound with no processing aid. The Rock Island Arsenal Operations Directorate will be using the new compound as soon as the T-seal injection mold has been modified to enlarge the sprues which should also improve flow.

Compound Updating

The results of the search for a substitute for the antioxidant Neozone D are shown in Tables 5 and 6, the former giving formulations, the latter showing physical properties. ANTOX N, an octylated diphenylamine, proved to be an adequate replacement for Neozone D in SBR and in neoprene compounds. Its efficacy during accelerated aging is best shown after exposure to air at 250° F. A loading of 2 pphr of ANTOX N appears to offer adequate protection to the vulcanizates, as noted by the good retention of tensile strength and elongation as compared to the control compounds.

Obturator Pads

Neoprene rubber obturator pads were compression-molded to the 175mm or 8-inch size from the same rubber compound as is specified on Dwg. 11578862 for the 155mm pad. Firing tests on these pads were conducted at ambient conditions at Jefferson Proving Ground (JPG), Madison, Indiana. Results to date on one pad show it to be serviceable after 679 rounds of zone 9 charge fired at the rate of 1 round every 2 minutes. Firing tests at low temperatures remain to be conducted at Aberdeen Proving Ground (APG).

Earlier studies had shown that the 155mm obturator pad functions at a much lower temperature than does the 175mm pad, even though both pads are made from the same rubber. The studies concluded that the difference in low temperature performance is due to the significant difference in the shape factors of the two pads. A method was devised for reducing the shape factor of the larger pad to make it the same as the shape factor of the smaller pad. This was accomplished by boring eleven, equally spaced, blind holes in the flat surface of the pad. The holes were 7/8 inch in diameter and 5/8 inch deep. The neoprene pads, with and without the blind holes, are shown in Figures 1 and 2, respectively. The modified pad is scheduled to be tested at ambient temperature at JPG and at low temperatures at APG, but no results are available at this writing.

Polymer Blends

1. Blends for use in barrier bags. The goal of this study was to increase the resistance to water-vapor penetration of the barrier bag for the 152mm combustible-cased round. The primary purpose of the bag is to deter penetration of moisture into the nitrocellulose portion of the round. Significant improvement in this property will have significant logistic implications because the rounds will have longer storage lives within the M551 vehicle. The addition of butyl rubber to the EPDM rubber now used in the fabrication of barrier bags significantly reduces the water vapor transmission rate, as shown in Table 7. The 50/50 blend provides the best balance of properties. The slightly lower tensile and tear strengths of the blend, compared to the EPDM compound, can be tolerated, as can the slightly poorer resistance to oil. The blend has improved set over the single polymer compound. Other properties remain unchanged. An important unanswered question is whether barrier bags can be injection-molded on a production basis with the 50/50 blend.

2. Blends for use in oil seals. For the past several years the Army has been considering the adoption of the flame-resistant hydraulic fluid (FRH) described in Specification MIL-H-46170 for use in the M60 tank. The advantages of this fluid over the currently used flammable fluid (MIL-H-6083) should be obvious. However, the fact that FRH and MIL-H-6083 fluids react in different ways with the standard rubber oil seals used in recoil mechanisms and gun mounts has been a cause for concern and was the reason behind this study. FRH tends to be an "extracting" fluid, that is, it has an affinity for the plasticizers in the oil seal rubber. The fluid extracts a portion of the plasticizers and causes the rubber seals to shrink in volume or at least causes them to swell to a lesser degree than if the fluid were "swelling" in nature. Fluid conforming to MIL-H-6083 is a "swelling" fluid and causes the standard rubber seals to increase in volume by about 9 percent. The standard seals have been designed to such dimensions that when they swell by about 7 to 10 percent, they perform properly to produce reasonably leak-free seals. FRH will swell the rubber less than this amount or, under certain conditions of time and temperature, will cause shrinkage. Either of these conditions will result in excessive leakage. In anticipation of a change from MIL-H-6083 to FRH, blends were prepared of nitrile rubber and SBR rubber. Nitrile is the basic polymer used in all oil seals. SBR is non-oil resistant and will produce swelling. As shown in Table 8, only 2 pphr of SBR increase the swell caused by FRH from about 4 to 7 percent. Four or six pphr SBR seem to be the desired amounts since the swell increases to the proper extent. The other measured properties of the 96/4 NBR/SBR blend as well as of the 94/6 blend do not differ significantly from the control nitrile compound.

3. Blends for use in obturator pads. The most important properties

of the compound currently used in the fabrication of all 155mm rubber obturator pads are shown in Table 9. The purpose of this study was to prepare blends that would have properties similar to these. The blends were developed from polymers that are more readily available from an energy requirement standpoint than is neoprene. Neoprene rubber, because it contains chlorine, is likely to be in short supply under conditions of strict energy conservation.

The blends that were developed are described in Tables 10 through 17. The properties of blends of NBR and a solution polymerized SBR, the former to impart oil resistance, the latter to provide functionality at low temperatures, are shown in Table 10. As expected, oil resistance became poorer as the amount of NBR decreased. Low-temperature flexibility was not significantly improved until the SBR content was 80 pphr. The 20/80 NBR/SBR blend might provide excellent obturator pads if the high-volume change in oil (+119%) can be tolerated. Attempts were made to improve the oil resistance of this blend by changing to Vanox A, methyl ethyl tuads, Durax curative system. Although oil resistance was improved, properties at low temperature became poorer.

The properties of a series of NBR/SBR blends that are cured with a sulfur-accelerator system are shown in Table 11. Oil resistance was markedly improved over the resistance of the tuad-cured blends of Table 10. However, flexibility at low temperatures was adversely affected to the point where the blends of Table 11 would be unsuitable for use in obturator pads.

The use of plasticizer to improve performance at low temperatures is shown in Table 12. Unfortunately, the reductions in tensile strength and hardness were too large, even though the low-temperature flexibility and other pertinent properties were acceptable as far as this application is concerned.

Attempts to increase the strength and hardness of the blends shown in Table 12 by the addition of more carbon black were successful, as shown in Table 13. The last listed blend containing 20 pphr of dioctyl sebacate plasticizer has properties quite similar to those of the neoprene rubber shown in Table 9. In fact, the blend has superior low-temperature flexibility. This compound is a likely choice for obturator pad application.

Data are listed in Table 14 for blends of NBR and an oil-extended solution-polymerized SBR. The oil did not provide any improvements in properties over blends previously discussed. Increasing the carbon black loading from 40 to 80 pphr and changing from a tuads cure to sulfur and accelerator provided improvements in oil resistance, but detracted from the low-temperature flexibility, as shown in Table 15.

Properties of blends of NBR and Cis-4 polybutadiene are shown in Table 16. The excellent low-temperature properties of the polybutadiene begin to show up when the polybutadiene content reaches 65 pphr. The 35/65 blend was chosen for further study because of its excellent balance of tensile strength, oil resistance, and low-temperature flexibility.

The above-mentioned blend from Table 16 was modified by the addition of more carbon black and dioctyl sebacate plasticizer. The results shown in Table 17 are outstanding. Again, the 35/65 blend shows excellent property balance consisting of high-tensile strength, very good resistance to oil, and low-temperature capabilities down to -81° F. (-63° C.). Two obturator pads (175mm) were fabricated from this blend at the request of the Project Manager's Office, M110E2. The PM is funding a project to have these pads proof-fired at ambient and low temperatures.

CONCLUSIONS

Phosphonitrilic vulcanizates exhibit excellent oil resistance and are functional over a broad temperature range. This polymer, in masterbatch form, is much easier to process on a two-roll mill than the gum elastomer itself. Efforts to increase the tensile strength of this material were unsuccessful.

Vanfre AP-2 processing aid improved the mold flow of a nitrile-based compound developed for oil-resistant seals without detracting from other desirable physical properties.

ANTOX N was found to be a suitable antioxidant to replace Neozone D that has been withdrawn from the market.

The neoprene 175mm obturator pad has shown significantly better service life than the current standard obturator pad. Placement of blind holes in the pad has effectively reduced the shape factor, thus low-temperature compressibility, in laboratory tests, has been improved.

A polymer blend of equal parts of EPDM and butyl rubbers, developed for potential use in the fabrication of 152mm barrier bags, proved to have a very significantly lower water-vapor transmission rate than the rubber in current production use. The production compound has a WVTR of 0.25 gram/100sq. inches/24 hours/0.030 inch thickness, whereas the newly developed blend has a rate of only 0.12. Other important properties of the blend are believed to be adequate for the barrier-bag application.

Polymer blends of NBR/SBR have been developed for potential use with FRH fluid. These blends remedy the problem of rubber shrinkage that occurs when FRH is used with the rubber oil-seals currently used in many weapon systems.

Several polymer blends have been developed for use in obturator pads if and when the currently used neoprene rubber becomes difficult to procure because of energy limitations.

RECOMMENDATIONS

Means of improving the tensile strength of phosphonitrilic vulcanizates should be pursued. Investigation of wetting agents would be of value for this purpose.

An awareness should be maintained of processing problems encountered by contractors or Army laboratories that are associated with the fabrication of rubber weapon components. Means should be sought to remedy these problems through the techniques of rubber compounding.

The evaluation of new elastomers and related materials should be continued to take advantage of new rubber technology. It is imperative to remain abreast of the state of the art due to changes of the availability of materials that are removed from the market because of OSHA regulations and material shortages.

Testing of 175mm neoprene obturator pads should be monitored so that appropriate compound changes can be made to insure better low-temperature service of these pads.

Compounds developed for potential use as barrier bags should be further evaluated in a PIP program, especially with the view of determining whether the compounds are readily injection moldable.

Much more work needs to be performed on polymer blends. The use of co-vulcanization agents, capable of vulcanizing both or all of the polymer constituents, needs to be stressed. Blends consisting of more than two polymers should be studied extensively since this field has been virtually untouched.

Table 1

PHOSPHONITRILIC RUBBER COMPOUND FORMULATIONS

<u>Compounding Ingredients</u>		<u>Parts by Weight</u>		
		<u>Z199</u>	<u>Z199-1</u>	<u>Z199-2</u>
PNF 200	} Received in masterbatch form from Firestone	100	100	100
Quso WR82		30	30	30
Stan Mag ELC		6	6	6
Stabilizer		2	2	2
Graphite		5	5	5
SE-33		5	5	5
Vul-Cup R		0.4	0.4	0.4
Hi Sil 233		5	10	

Compression-molded 30 minutes @ 340° F. (151°C.)

Table 2

PHYSICAL PROPERTIES OF PHOSPHONITRILIC VULCANIZATES

Properties Measured	Z199	Z199-1	Z199-2
Tensile strength, psi (MPa)	1140 (7.8)	990 (6.8)	970 (6.6)
Modulus @ 100% E, psi (MPa)	520 (3.6)	660 (4.5)	650 (4.4)
Elongation, %	160	150	150
Hardness, Shore A	50	60	63
Compression set, 70 hrs/302°F (150°C), %	35	31	43
Ozone, 50 ppm @ 104°F (40°C)	No cracks	No cracks	No cracks
Low-temperature brittleness @ -67°F (-55°C)	Pass	Pass	Pass
<u>70 Hrs/302°F (150°C)/Air:</u>			
Tensile strength, psi (MPa)	1000	1110	990
Elongation, %	150 (1.0)	170 (1.2)	160 (1.1)
Hardness, Shore A	56	57	60
Flat Bend	Pass	Pass	Pass
<u>70 Hrs/212°F (100°C)/MIL-H-6083 Hydraulic Fluid:</u>			
Hardness change, points	+7	+6	+7
Volume change, %	+3	+3	+4

Table 3

NITRILE RUBBER COMPOUND FORMULATIONS

<u>Compounding Ingredients</u>	<u>Parts by Weight</u>		
	<u>N209-10</u>	<u>N209-11</u>	<u>N209-12</u>
Chemigum N917	95	95	95
Paracrill B	5	5	5
Zinc oxide	5	5	5
Vanax A	1.1	1.1	1.1
Methyl Ethyl Tuads	2.3	2.3	2.3
Durax	1.75	1.75	1.75
Maglite D	5	5	5
Age Rite Resin D	1.5	1.5	1.5
Age Rite Superflex	1.5	1.5	1.5
Philblack N550	35	35	35
Statex 160	50	50	50
Plasticizer DOS	10	10	10
Plastolien 9058	10	10	10
Vanfre AP-2		1.5	3

Compression-mold test pads 30 minutes @ 307° F (153° C)
 Suggested injection-molding conditions: 2 - 3 minutes @ 400° F (204° C)

Table 4

PHYSICAL PROPERTIES OF NITRILE VULCANIZATES
WITH AND WITHOUT A PROCESSING AID

<u>Properties Measured</u>	<u>Parts by Weight</u>		
	<u>N209-10</u>	<u>N209-11</u>	<u>N209-12</u>
Tensile strength, psi (MPa)	2500 (17.2)	2490 (17.2)	2510 (17.2)
Modulus @ 200% E, psi (MPa)	1890 (13.0)	1920 (13.2)	1750 (12.0)
Elongation, %	230	250	260
Hardness, Shore A	71	71	70
Compression set, 70 hrs/212°F (100°C), %	28	25	25
<u>70 Hrs 212°F (100°C)/Air:</u>			
Tensile strength, psi (MPa)	2480 (17.0)	2420 (16.6)	2320 (16.0)
Elongation, %	200	180	180
Hardness, Shore A	78	77	76

Table 5

FORMULATIONS OF SBR AND NEOPRENE COMPOUNDS CONTAINING NEOZONE D AND ANTOX N ANTIOXIDANTS

Compounding Ingredients	S255	S255-1	Parts by Weight				M127	M127-1	M127-2	M127-3
			S255-2	S255-3	S255-4	S255-5				
SBR 1609	145	145	145	145	145	100	100	100	100	
Neoprene WD										
Zinc oxide	4	4	4	4	4					
Stearic acid	2	2	2	2	2					
Santocure	1	1	1	1	1					
Sulfur	1.75	1.75	1.75	1.75	1.75					
Maglite D						4	4	4	4	
Statex 125H						40	40	40	40	
Plasticizer DOS						35	35	35	35	
NA-22						1	1	1	1	
UOP 88						5	5	5	5	
Neozone D		1	2							
ANTOX N				1	2		1	2	3	

Compression-mold 30 minutes @ 307°F (153°C)

Table 6

PHYSICAL PROPERTIES OF SBR AND NEOPRENE VULCANIZATES
WITH VARIOUS LEVELS OF ANTIOXIDANTS

Properties Measured	S255	S255-1	S255-2	S255-3	S255-4	M127	M127-1	M127-2	M127-3
<u>Original:</u>									
Tensile strength, psi(MPa)	4100(28.2)	3850(26.5)	3700(25.4)	4050(27.9)	4000(27.6)	2390(16.4)	2160(14.8)	2420(16.7)	2510(17.2)
Modulus @ 300% E, psi(MPa)	930(6.4)	840(5.8)	960(6.6)	910(6.2)	790(5.4)	1700(11.7)	1610(11.0)	1580(10.8)	1480(10.2)
Elongation, %	770	680	650	680	720	320	350	400	400
Hardness, Shore A	58	58	58	59	58	53	52	49	48
<u>70 Hrs/212°F(100°C)/Air:</u>									
Tensile strength, psi(MPa)	3390(23.4)	2630(18.1)	2990(20.6)	3470(23.9)	3020(20.8)	2050(14.1)	2420(16.6)	2290(15.8)	2210(15.2)
Modulus @ 300% E, psi(MPa)	2730(18.8)	2520(17.4)	2270(15.6)	2550(17.6)	2310(15.9)	1560(10.7)	1480(10.2)	1350(9.3)	1230(8.4)
Elongation, %	360	310	360	390	360	350	400	400	390
Hardness, Shore A	68	68	66	66	66	51	51	51	50
<u>70 Hrs/250°F(121°C)/Air:</u>									
Tensile strength, psi(MPa)	1580(10.8)	1910(13.2)	2170(15.0)	2340(16.1)	2300(15.8)	1750(12.0)	2350(16.2)	2440(16.8)	2390(16.4)
Elongation, %	120	150	150	180	180	200	300	320	340
Hardness, Shore A	76	76	75	73	73	65	62	63	60

Table 7

POLYMER BLENDS FOR USE IN BARRIER BAGS

Compounding Ingredients	Parts by Weight					
	100	75	50	25	0	
Nordel 1040 (EPDM)	0	25	50	75	100	
Butyl 325	50	50	50	50	50	
Philblack N550 (FEF)	20	20	20	20	20	
Necton 60	1	1	1	1	1	
Stearic acid	5	5	5	5	5	
Zinc oxide	0.5	0.5	0.5	0.5	0.5	
Altax	1	1	-1	1	1	
Methyl Tuads	2	2	2	2	2	
<u>Physical Properties</u>						
Tensile strength, psi (MPa)	2040 (14.0)	1810 (12.4)	1630 (11.2)	1510 (10.4)	1340 (9.2)	
Modulus/300%, psi (MPa)	670 (4.6)	600 (4.1)	650 (4.4)	640 (4.4)	520 (3.6)	
Elongation, %	685	665	610	550	605	
Hardness, Shore A	60	62	61	60	58	
Compression Set, ASTM D395 Method B, 70 Hrs/212°F (100°C), %	50	49	41	41	41	
Tension set, ASTM D412, %	15	16	12	15	16	
Tear strength, ASTM D624, Die C, lbs/in (kN/m)	193 (33.8)	193 (33.8)	176 (30.8)	160 (28.0)	145 (25.4)	
Low-Temperature Flexibility, ASTM D1043, Temp. where Young's Modulus = 10,000 psi (69MPa), °F (°C)	-67 (-55)	-66 (-54)	-65 (-54)	-65 (-54)	-66 (-54)	
<u>Aged 70 Hrs/125°F (52°C)/MIL-H-6083 Fluid:</u>						
Tensile strength, psi (MPa)	570 (3.9)	540 (3.7)	450 (3.1)	470 (3.2)	340 (2.3)	
Elongation, %	185	215	175	175	190	
Hardness, Shore A	30	30	30	30	30	
<u>Aged 70 Hrs/Air/212°F (100°C):</u>						
Tensile strength, psi (MPa)	2040 (14.0)	1700 (11.7)	1610 (11.0)	1450 (10.0)	1340 (9.2)	
Modulus/300%, psi (MPa)	780 (5.4)	780 (5.4)	830 (5.7)	890 (6.1)	630 (4.3)	
Elongation, %	520	530	530	485	605	
Hardness, Shore A	63	61	60	60	54	
Water-Vapor Transmission Rate, Grams/100 sq. inches/24 hrs/0.030 inch thickness	0.248	0.165	0.121	0.089	0.046	

Table 8

POLYMER BLENDS FOR USE IN OIL SEALS

Compounding Ingredients	Parts by Weight					
	95	93	91	89	87	
Chemigum N917 (NBR) (20% acrylonitrile)						
Paracril B (NBR) (29.5 acrylonitrile)						
Stereon 700 (SBR)	5	5	5	5	5	5
Philblack N550 (FEF)	0	2	4	6	8	8
Statex 160 (SAF)	35	35	35	35	35	35
Diocetyl Sebacate	10	10	10	10	10	10
Plastolien 9058	10	10	10	10	10	10
Zinc oxide	5	5	5	5	5	5
Vanax A	1.1	1.1	1.1	1.1	1.1	1.1
Methyl Ethyl Tuads	2.3	2.3	2.3	2.3	2.3	2.3
Durax	1.75	1.75	1.75	1.75	1.75	1.75
Age Rite Resin D	1.5	1.5	1.5	1.5	1.5	1.5
Age Rite Superflex	1.5	1.5	1.5	1.5	1.5	1.5
Maglite D	1.5	1.5	1.5	1.5	1.5	1.5
<u>Physical Properties</u>						
Tensile strength, psi (MPa)	2650 (18.2)	2600 (17.9)	2680 (18.4)	2220 (15.2)	2600 (17.9)	2600 (17.9)
Elongation, %	290	285	290	265	265	265
Hardness, Shore A	73	75	75	75	76	76
Compression Set, ASTM D395 Method B, 70 Hrs/212° F (100° C), %	25	21	22	22	22	22
<u>Volume Change After Immersion in FRH:</u>						
70 Hrs/158° F (70° C), %	+5.5	+7	+6	+7	+7	+7
70 Hrs/212° F (100° C), %	+4.6	+7.5	+7.5	+11.4	+20	+20
70 Hrs/275° F (135° C), %	+3.4	+7.8	+10	+10.7	+12	+12
<u>Aged 70 Hrs/212° F (100° C)/ASTM #3 Oil:</u>						
Tensile strength, psi (MPa)	2310 (15.9)	2210 (15.2)	2520 (17.4)	1830 (12.6)	2190 (15.0)	2190 (15.0)
Elongation, %	250	240	255	225	240	240
Hardness, Shore A	66	68	66	65	64	64
Volume change, %	+15	+18	+20	+20	+22	+22
<u>Aged 70 Hrs/Air/212° F (100° C):</u>						
Tensile strength, psi (MPa)	2430 (16.7)	2520 (17.4)	2420 (16.6)	2050 (14.1)	2510 (17.2)	2510 (17.2)
Elongation, %	250	220	225	200	225	225
Hardness, Shore A	83	86	82	85	85	85

Table 9

PHYSICAL PROPERTIES OF NEOPRENE OBTURATOR PAD RUBBER COMPOUND

<u>Physical Properties</u>	<u>M118-3</u>
Tensile strength, psi (MPa)	2260 (15.6)
Modulus @ 200% E, psi (MPa)	1470 (10.1)
Elongation, %	260
Hardness, Shore A	68
Compression Set, ASTM D395	
Method B, 70 Hrs/212° F (100° C), %	33
Volume change,	
70 Hrs/212° F (100° C)/ASTM #3 oil, %	+40
Low-Temperature Flexibility	
ASTM D1043, Temp. Where Young's	
Modulus = 10,000 psi (69 MPa), ° F (° C)	-57 (-49)

Table 10

NBR/SOLUTION POLYMERIZED SBR BLENDS-TUAD CURE

<u>Compounding Ingredients</u>	<u>Parts by Weight</u>					
Chemigum N917 (NBR)	100	80	60	40	20	0
(20% acrylonitrile)	0	20	40	60	80	100
Stereon 700 (SBR)	40	40	40	40	40	40
Philblack N550 (FEF)	0.5	0.5	0.5	0.5	0.5	0.5
Stearic acid	5	5	5	5	5	5
Zinc oxide	1	1	1	1	1	1
Age Rite Resin D	3.5	3.5	3.5	3.5	3.5	3.5
Methyl Tuads						
<u>Physical Properties</u>						
Tensile strength, psi (MPa)	2950 (20.3)	2710 (18.6)	2460 (16.9)	2320 (16.0)	2110 (14.5)	1710 (11.8)
Elongation, %	440	445	465	465	480	400
Hardness, Shore A	69	69	70	70	70	70
Compression Set, ASTM D395						
Method B, 70 Hrs/212°F	15	15	14	17	26	17
(100°C), %						
Volume change, 70 Hrs/212°F	+38	+56	+70	+97	+119	+131
(100°C)/ASTM #3 oil, %						
Low Temperature Flexibility,						
ASTM D1043, Temp. where Young's						
Modulus = 10,000 psi						
(69MPa), °F (°C)	-36 (-38)	-33 (-36)	-36 (-36)	-44 (-42)	-80 (-62)	-92 (-69)
Aged 70 Hrs/Air/212°F (100°C):						
Tensile strength, psi (MPa)	3230 (22.2)	2890 (19.9)	2610 (18.0)	2170 (15.0)	2430 (16.7)	1790 (12.3)
Elongation, %	430	380	395	355	440	335
Hardness, Shore A	70	71	71	73	73	73

Table .11

NBR/SOLUTION POLYMERIZED SBR BLENDS-SULFUR ACCELERATOR CURE

Compounding Ingredients	Parts by Weight					
	80	75	70	65	60	
Stereon 700 (SBR)						
Chemigum N917 (NBR)	20	25	30	35	40	
(20% acrylonitrile)	40	40	40	40	40	
Philblack N550 (FEF)	0.5	0.5	0.5	0.5	0.5	
Stearic Acid	5	5	5	5	5	
Zinc oxide	2	2	2	2	2	
Age Rite Resin D	0.6	0.75	0.90	1.05	1.20	
Altax	0.75	0.88	1.05	1.23	1.40	
Methyl Tuads	0.64	0.60	0.56	0.52	0.48	
Santocure	1.6	1.5	1.4	1.3	1.2	
Sulfur						
<u>Physical Properties</u>						
Tensile strength, psi (MPa)	1610 (11.0)	1870 (12.8)	1650 (11.4)	1590 (11.0)	1800 (12.4)	
Elongation, %	215	265	215	205	235	
Hardness, Shore A	79	79	78	77	76	
Compression Set, ASTM D395						
Method B, 70 Hrs/212°F	18	16	11	11	13	
(100°C), %						
Volume change, 70 Hrs/212°F	+94	+93	+83	+81	+77	
(100°C)/ASTM #3 oil, %						
Low-Temperature Flexibility ASTM						
D1043, Temp. Where Young's Modulus	-55 (-48)	-39 (-39)	-22 (-30)	-22 (-30)	-22 (-30)	
= 10,000 psi (69 MPa), °F (°C)						
<u>Aged 70 Hrs/Air/212°F (100°C):</u>						
Tensile strength, psi (MPa)	1440 (9.9)	1710 (11.8)	1810 (12.4)	1770 (12.2)	1690 (11.6)	
Elongation, %	175	205	205	210	195	
Hardness, Shore A	82	80	81	81	80	

Table 12

NBR/SOLUTION POLYMERIZED SBR BLENDS CONTAINING PLASTICIZER

<u>Compounding Ingredients</u>	<u>Parts by Weight</u>			
Chemigum N917 (NBR) (20% acrylonitrile)	50	50	50	50
Stereon 700 (SBR)	50	50	50	50
Philblack N550 (PEF)	40	40	40	40
Stearic acid	0.5	0.5	0.5	0.5
Zinc oxide	5	5	5	5
Age Rite Resin D	1	1	1	1
Methyl Tuads	3.5	3.5	3.5	3.5
Diocetyl Sebacate Plasticizer	0	10	15	20
<u>Physical Properties</u>				
Tensile strength, psi (MPa)	2080 (14.3)	1700 (11.7)	1490 (10.2)	1490 (10.2)
Elongation, %	415	430	455	465
Hardness, Shore A	69	62	59	55
Compression Set, ASTM D395, Method B, 70 Hrs/212°F (100°C), %	22	21	21	22
Volume change, 70 Hrs/212°F (100°C)/ ASTM #3 oil, %	+107	+106	+107	+95
Low-Temperature Flexibility, ASTM D1043, Temp. Where Young's Modulus = 10,000 psi (69 MPa), °F (°C)	-44 (-42)	-53 (-47)	-58 (-50)	-65 (-54)
Aged 70 Hrs/Air/212°F (100°C):				
Tensile strength, psi (MPa)	2070 (14.2)	1990 (13.7)	1510 (10.4)	1690 (11.6)
Elongation, %	350	410	360	390
Hardness, Shore A	71	66	64	60
				1400 (9.6)
				420
				54

Table 13
NBR/SOLUTION POLYMERIZED SBR BLENDS CONTAINING PLASTICIZER

Compounding Ingredients	Parts by Weight				
Chemigum N917 (NBR) (20% acrylonitrile)	50	50	50	50	50
Stereon 700 (SBR)	50	50	50	50	50
Phylblack N550 (FEF)	60	60	60	60	60
Stearic acid	0.5	0.5	0.5	0.5	0.5
Zinc oxide	5	5	5	5	5
Age Rite Resin D	1	1	1	1	1
Methyl Tuads	3.5	3.5	3.5	3.5	3.5
Dioctyl Sebacate Plasticizer	0	10	15	20	20
Physical Properties					
Tensile strength, psi (MPa)	2150 (14.8)	2140 (14.7)	1760 (12.1)	1660 (11.4)	1530 (10.5)
Elongation, %	275	300	315	325	330
Hardness, Shore A	79	74	71	68	62
Compression Set, ASTM D395, Method B, 70 Hrs/212° F (100° C), %	20	19	22	21	23
Volume change, 70 Hrs./212° F (100° C)/ ASTM #3 oil, %	+86	+81	+80	+82	+81
Low-Temperature Flexibility, ASTM D1043 Temp. Where Young's Modulus = 10,000 psi (69 MPa), ° F (° C)	-37 (-38)	-43 (-42)	-48 (-44)	-56 (-49)	-64 (-53)
Aged 70 Hrs/Air/212° F (100° C):					
Tensile strength, psi (MPa)	2550 (17.6)	2260 (15.6)	2070 (14.2)	1960 (13.5)	1850 (12.7)
Elongation, %	255	275	275	315	310
Hardness, Shore A	84	80	75	70	69

Table 14

NBR/OIL EXTENDED, SOLUTION POLYMERIZED SBR BLENDS (LOW CARBON BLACK)

Compounding Ingredients

	<u>Parts by Weight</u>				
Chemigum N917 (NBR) (20% acrylonitrile)	100	80	60	40	20
Stereon 750 (SBR)	0	27.5	55	82.5	110
(37.5 phr aromatic oil)	40	40	40	40	40
Philblack N550 (FEF)	0.5	0.5	0.5	0.5	0.5
Stearic acid	1	1	1	1	1
Age Rite Resin D	5	5	5	5	5
Zinc oxide	3.5	3.5	3.5	3.5	3.5
Methyl Tuads					

Physical Properties

Tensile strength, psi (MPa)	2950 (20.3)	2410 (16.6)	2210 (15.2)	2070 (14.2)	1560 (10.7)	1320 (9.0)
Elongation, %	440	470	450	605	665	620
Hardness, Shore A	69	62	58	51	48	47
Compression Set, ASTM D395, Method B, 70 Hrs/212°F (100°C), %	15	14	16	18	15	23
Volume change, 70 Hrs/212°F (100°C)/ ASTM #3 oil, %	+38	+54	+74	+93	+120	+151
Low-Temperature Flexibility, ASTM D1043, Temp. Where Young's Modulus = 10,000 psi (69 MPa), °F (°C)	-36 (-38)	-36 (-38)	-34 (-37)	-44 (-42)	-76 (-60)	-80 (-62)

Aged 70 Hrs/Air/212°F (100°C):

Tensile strength, psi (MPa)	3230 (22.2)	2620 (18.0)	2030 (14.0)	1980 (13.6)	1460 (10.0)	1170 (8.0)
Elongation, %	430	365	365	470	435	415
Hardness, Shore A	70	65	65	59	55	51

Table 15

NBR/OIL EXTENDED, SOLUTION POLYMERIZED SBR BLENDS (HIGH CARBON BLACK)

Compounding Ingredients	Parts by Weight						
	100	80	60	40	20	0	
Chemigum N917 (NBR) (20% acrylonitrile)							
Stereon 750 (SBR) (37.5 phr aromatic oil)	0	27.5	55	82.5	110	137.5	
Philblack N550 (FEF)	80	80	80	80	80	80	
Stearic acid	0.5	0.5	0.5	0.5	0.5	0.5	
Zinc oxide	5	5	5	5	5	5	
Age Rite Resin D	2	2	2	2	2	2	
Sulfur	0	0.4	0.8	1.2	1.6	2	
Santogure	0	0.16	0.32	0.48	0.64	0.8	
Altax	3	2.4	1.8	1.2	0.6	0	
Methyl Tuads	3.5	2.8	2.1	1.4	0.7	0	
<u>Physical Properties</u>							
Tensile strength, psi (MPa)	2830 (19.4)	2740 (18.8)	2160 (14.8)	2020 (13.9)	2130 (14.6)	1400 (9.6)	
Elongation, %	250	185	180	190	280	470	
Hardness, Shore A	85	89	85	82	75	59	
Compression Set, ASTM D395, Method B, 70 Hrs/212°F (100°C), %	17	12	13	11	16	67	
Volume change, 70 Hrs/212°F (100°C)/ ASTM #3 oil, %	+31	+32	+38	+46	+72	+196	
Low-Temperature Flexibility, ASTM D1043, Temp. Where Young's Modulus = 10,000 psi (69 MPa), °F (°C)	-13 (-25)	-13 (-25)	-15 (-26)	-8 (-22)	-43 (-42)	-69 (-56)	
<u>Aged 70 Hrs/Air 212°F (100°C):</u>							
Tensile strength, psi (MPa)	3300 (22.7)	2400 (16.5)	2240 (15.4)	2030 (14.0)	2130 (14.6)	1580 (10.8)	
Elongation, %	255	170	155	155	210	255	
Hardness, Shore A	90	91	90	90	82	70	

Table 16

NBR/CIS-4 POLYBUTADIENE BLENDS

Compounding Ingredients	Parts by Weight									
	100	75	50	45	40	35	30	25	20	15
Chemigum N917 (NBR) (20% acrylonitrile)	0	25	50	55	60	65	70	75	80	85
Cis-4-Polybutadiene	40	40	40	40	40	40	40	40	40	40
Philblack N550 (FEP)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Stearic acid	5	5	5	5	5	5	5	5	5	5
Zinc oxide	1	1	1	1	1	1	1	1	1	1
Age Rite Resin D	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Methyl Tuads										
<u>Physical Properties</u>										
Tensile strength, psi (MPa)	2950 (20.3)	2590 (17.8)	2240 (15.4)	2220 (15.2)	1980 (13.6)	1990 (13.7)	1650 (11.4)	1590 (11.0)		
Elongation, %	440	430	380	435	440	415	375	370		
Hardness, Shore A	69	70	69	65	65	66	66	69		
Compression Set, ASTM D395 Method B, 70 Hrs/212° F (100° C), %	15	13	14	20	14	13	13	14		
Volume change, 70 Hrs/212° F (100° C)/ASTM #3 oil, %	+38	+61	+86	+92	+100	+101	+108	+111		
Low Temperature Flexibility ASTM D1043, Temp. Where Young's Modulus = 10,000 psi (69 MPa), ° F (° C)	-36 (-38)	-37 (-38)	-46 (-43)	-46 (-43)	-53 (-47)	-65 (-54)	BeLow -100 (-73)	BeLow -100 (-73)		
<u>Aged 70 Hrs/Air/212° F (100° C):</u>										
Tensile strength, psi (MPa)	3230 (22.2)	2280 (15.7)	2220 (15.2)	2580 (17.8)	2120 (14.6)	1860 (12.8)	1880 (13.0)	1610 (11.0)		
Elongation, %	430	345	330	355	375	320	330	355		
Hardness, Shore A	70	70	70	70	70	70	70	70		

Table 17

NBR/CIS-4 POLYBUTADIENE BLENDS CONTAINING PLASTICIZER

<u>Compounding Ingredients</u>	<u>Parts by Weight</u>					
Chemigum N917 (NBR)	35	35	35	35	35	35
(20% acrylonitrile)	65	65	65	65	65	65
Cis-4-Polybutadiene	60	60	60	60	60	60
Phlblack N550 (FEF)	0.5	0.5	0.5	0.5	0.5	0.5
Stearic acid	5	5	5	5	5	5
Zinc oxide	1	1	1	1	1	1
Age Rite Resin D	3.5	3.5	3.5	3.5	3.5	3.5
Methyl Tuads	0	5	10	15	20	20
Dioctyl Sebacate Plasticizer						
<u>Physical Properties</u>						
Tensile strength, psi	1940 (13.4)	2290 (15.8)	2130 (14.6)	1820 (12.5)	1970 (13.6)	
Elongation, %	260	315	370	370	395	
Hardness, Shore A	83	80	74	69	69	
Compression Set, ASTM D395						
Method B, 70 Hrs/212°F	14	14	17	19	19	
(100°C), %						
Volume change, 70 Hrs/212°F						
(100°C)/ASTM #3 oil, %	+87	+85	+86	+89	+83	
Low Temperature Flexibility, ASTM						
D1043, Temp. Where Young's						
Modulus = 10,000 psi						
(69 MPa), °F (°C)	-49 (-45)	-57 (-49)	-67 (-55)	-73 (-58)	-81 (-63)	
<u>Aged 70 Hrs/Air/212°F (100°C):</u>						
Tensile strength, psi (MPa)	2160 (14.8)	2110 (14.5)	2060 (14.2)	1950 (13.4)	1830 (12.6)	
Elongation, %	230	225	295	330	320	
Hardness, Shore A	85	81	78	73	70	

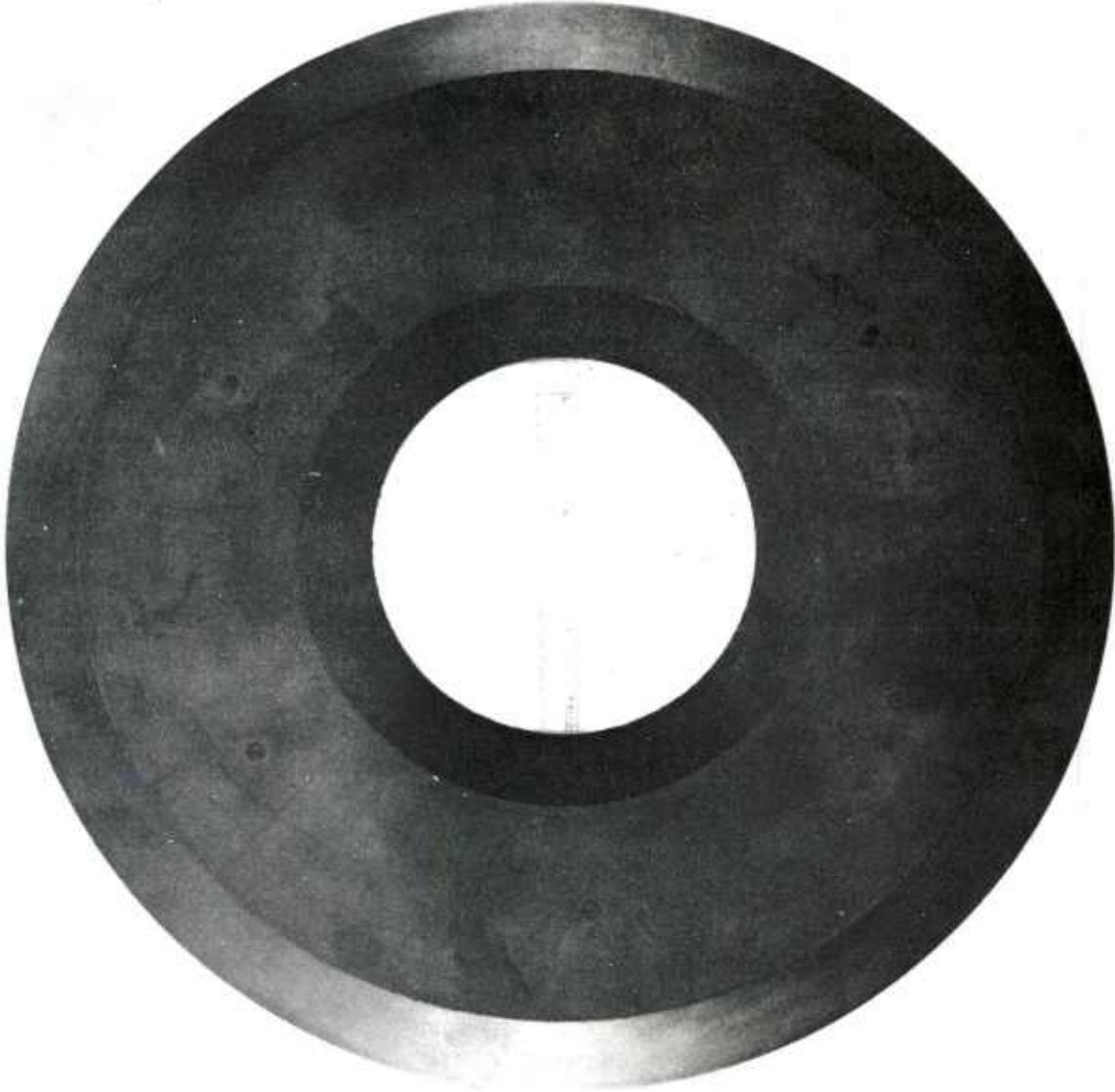


Figure 1. Neoprene Rubber Obturator Pad, 175mm

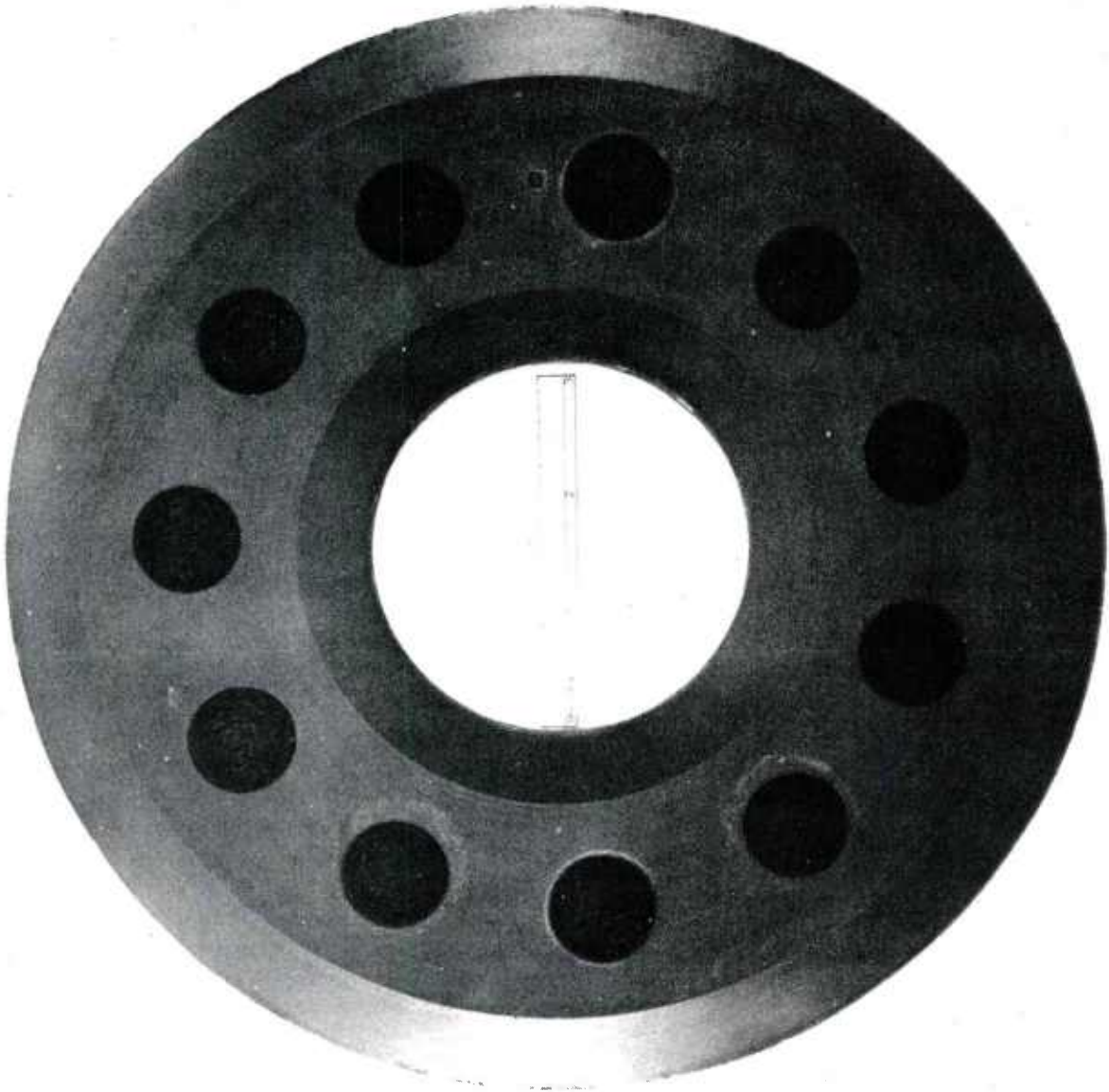


Figure 2. Neoprene Rubber Obturator Pad (Modified), 175mm

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tables, (DA IT162105AH84, PRON AW-6-ROO03-01-AW-MS,
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