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AFML-TR-66-73 April 1966

DEVELOPMENT OF A LONG LIFE O-RING COMPOUND FOR USE IN AIRCRAFT HYDRAULIC SYSTEMS USING MIL-H-5606 FLUIDS AT PRESSURES UP TO 3000 PSI AND TEMPERATURES RANGING FROM -65°F to +275°F

Paul Nenninger
Republic Aviation Division
Fairchild Hiller Corporation

Technical Report AFML-TR-66-73
April 1966

Materials Engineering Branch
Materials Applications Division
Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

NOTICES

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REPUBLIC AVIATION DIVISION

5 July 1966
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Subject: Contract AF33(615)-1668
Final Report Distribution

To: Air Force Materiels Laboratory
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Ohio 45433

1. By this letter Republic Aviation Division of Fairchild Hiller Corporation is making distribution of the Final Report prepared under subject contract.

2. In accordance with the distribution list provided by the Air Force Materiels Laboratory, this report AFML-TR-66-73 entitled "Development of a Long Life "O" Ring Compound, for use in Aircraft Hydraulic Systems, Using MIL-H-5606 Fluids, at Pressures up to 3000 psi, and Temperatures ranging from -65°F to +275°F", dated April 1966, summarizes the work performed under the contract.

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AFML-TR-66-73

DEVELOPMENT OF A LONG LIFE O-RING COMPOUND FOR USE IN AIRCRAFT HYDRAULIC SYSTEMS USING MIL-H-5606 FLUIDS AT PRESSURES UP TO 3000 PSI AND TEMPERATURES RANGING FROM -65°F to +275°F

Paul Nenninger

FOREWORD

This report was prepared by Republic Aviation Division of Fairchild Hiller Corporation, Farmingdale, Long Island, New York under USAF Contract AF 33(615)-1668. The contract was conducted under Project No. 7381, "Materials Applications", Task No. 738101, "Exploratory Design and Prototype Development." Administration was under the Materials Applications Division, Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, with Mr. P. A. House acting as Project Engineer.

This work was supported by the Director's Discretionary Fund.

The report covers work conducted during the period of July 1964 to March 1966. The manuscript was released by the author 1 March 1966 for publication as an AFML Technical Report.

The program was conducted with Mr. P. Nenninger as principal investigator, under the direction of Mr. R. Schroeder, Manager - Fluid Systems. The elastomeric compounding efforts in the program were subcontracted to Reliable Rubber Products Company, Eddington, Bucks County, Pennsylvania, and were under the direction of Mr. J. B. Johnson.

This technical report has been reviewed and is approved.

Albert Olevitch
ALBERT OLEVITCH, Chief
Materials Engineering Branch
Materials Applications Division
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ABSTRACT

This Summary Technical Report describes the program for the development of a long life O-ring compound for use in aircraft hydraulic systems using MIL-H-5606 fluids at pressures up to 3000 psi and temperatures ranging from -65°F to +275°F. Compounding and blending efforts conducted during the program explored fluoroelastomers, polyacrylates, butadiene-acrylonitrile copolymers, epichlorohydrin elastomers, propylene-oxide rubber, polyurethane elastomers, chlorosulfonated polyethylenes, silicones, and others. Static and dynamic O-ring evaluations conducted on MIL-P-25732 buna N compounds confirmed contentions that this compound has limited heat resistance at 275°F, especially when it experiences some exposure to air. The same tests conducted on MIL-R-25897 fluoroelastomer compounds have shown that they have poor compression set characteristics, low temperature limitations, and poor extrusion resistance. Two compounds developed during the program exhibited performance superior to the aforementioned Military Specification compounds when evaluated in static and dynamic O-ring tests. The first of these compounds utilized Hydrin 200, a copolymer of epichlorohydrin with ethylene oxide produced by the B. F. Goodrich Company; the other was an ECD-487 (E. I. Du Pont de Nemours low temperature Viton) compound. Performance evaluations of the epichlorohydrin O-rings indicated that an increase in service life of 50 to 100% can be expected over buna N compounds under static and dynamic conditions when completely immersed in hydraulic fluid. In addition, 100 to 200% increase in service life can be expected when the seals are partially exposed to air. There is no increase in life for the ECD-487 over buna N when completely immersed in hydraulic fluid, but there is an increase of 150 to 300% when partially exposed to air. Of the two, the Hydrin formulation is preferred since it survived the most hours of O-ring testing in three of the four tests conducted. In addition, it may be easily processed and is moderately priced. It is anticipated that this copolymer will be available in production quantities in the future.

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POLYMER MANUFACTURERS AND THEIR PRODUCTS

A vast number of experimental and production polymers were used in the compounds developed for this program. Appreciation is expressed herein to the polymer manufacturers for their cooperation, and for the technical advice they gave concerning the use of their polymers. Because these polymers are frequently refered to throughout the text and in the recipe tables, a list of manufacturers and their polymers is provided for the convenience of the reader.

Manufacturer	Polymer Trade Names
American Cyanamid Co.	Cyanacril
Dow Corning Corp.	Silastic
E.I. Du Pont de Nemours and Co., Inc.	Adiprene, Hypalon, Nordel, Viton, ECD, and Neoprene
Enjay Chemical Co., Div. of Humble Oil and Refining Co.	Butyl HT
General Electric Co.	G.E. S.E. - 450
General Tire and Rubber Co.	Genthane and Dynagen
B.F. Goodrich Chemical Co. Div. of B.F. Goodrich Co.	Hycar, CHR Rubber, and Hydrin
Goodyear Tire and Rubber Co.	Ameripol and Chemigum
Minnesota Mining and Manufacturing Co.	Kel F and Fluorel
Naugatuck Chemical Div. of U.S. Rubber Co.	Paracril
Phillips Chemical Co. Subsidiary of Phillips Petroleum Co.	Phillips Cis, and Philiprene
Thiokol Chemical Corp.	Elastothane and Nitroso Rubber
Naftone, Inc.	Leveprene
U.S. Industrial Chemicals	Ultrathene

SECTION I

INTRODUCTION

Existing MS-28775 O-rings have a limited life at their upper temperature limit. At 275°F, compression set and hardening occur. When these conditions are coupled with material shrinkage at low temperature, excessive seal leakage frequently results. This problem can best be minimized by the development of an improved O-ring compound that is (1) capable of longer life at 275°F, (2) still retains good low temperature properties and (3) is abrasion and extrusion resistant. It was the purpose of this program to develop such a compound.

In order to achieve this objective, the program approach stressed the following research undertakings:

- Compounding of fluoroelastomeric materials, with special emphasis on improved fillers and plasticizers and new polymers such as ECD-487 (E.I. Du Pont de Nemours low temperature Viton) and others.
- Compounding of polyacrylate materials to explore new polymers being developed.
- Compounding of polyurethane elastomers to meet the -65°F to 275°F requirements.
- Formulation changes in butadiene-acrylonitrile copolymers.
- Blending of elastomeric materials, including fluoroelastomers, silicones, ethylene propylene, Buna N, propylene oxide, chlorosulfonated polyethylene, and polyurethane.
- Investigation of new polymeric materials, such as epichlorohydrin rubber, which appear applicable to the program requirement.

The merit of compounds developed was first determined by material property tests. Those showing promising properties were then molded into O-rings and subjected to realistic evaluation tests.

These evaluations were conducted in a manner similar to that set forth in Aerospace Recommended Practice 820 (ARP-820) issued by the Society of Automotive Engineers, Inc. This method of testing emphasizes long term service of static and dynamic seals at 275°F while still retaining -65°F capability in 3000 psi hydraulic systems that use MIL-H-5606 fluids.

A proposed military specification which outlines the performance requirements and test procedures which could be used to qualify compounds having long life capability at 275°F is presented in Appendix I.

The ingredients, cure schedules, and properties of all experimental compounds developed under this program are presented in Appendix II.

A description of the compounding effort, test program, conclusions and recommendations are presented in Sections II, III, IV, and V, respectively.

TABLE I. PROPERTIES OF COMPOUNDS CONFORMING TO SPECIFICATIONS MIL-P-25732 AND MIL-R-25897

	SOURCE "A"		SOURCE "B"	
	MIL-P-25732	MIL-R-25897	MIL-P-25732	MIL-R-25897
Original Properties				
Shore A hardness	76	75	78	70
Tensile strength, psi	2009	2029	2276	2370
Elongation	200%	270%	180%	280%
Tensile stress, 100%, psi	812	549	1180	600
Temperature retraction	-50°F	-1°F	-50°F	+4°F
Oil-Aged 168 hr/275°F MIL-H-5606				
Shore A hardness	75 (-1)	75 (0)	83 (+5)	74 (-2)
Tensile strength, psi	1075 (-46%)	2006 (-1%)	812 (-64%)	2341 (-1%)
Elongation	89%(-55%)	260%(-4%)	40%(-78%)	240%(-14%)
Tensile stress, 100%, psi	--	547 (0)	--	649 (-8%)
Volume change	+7.1%	+2.5%	+8.4%	+2.6%
Air-Aged 96 hr/275°F				
Shore A hardness	98 (+22)	78 (+3)	98 (+20)	80 (+4)
Tensile strength, psi	1970 (-2%)	2162 (+6%)	2023 (-11%)	2340 (-1%)
Elongation	40%(-80%)	257%(-4%)	30%(-83%)	235%(-14%)
Tensile stress, 100%, psi	--	625 (+13%)	--	694 (+15%)
Compression Set				
70 hr/275°F	44%	15%	46%	25%

1. FLUOROELASTOMERIC COMPOUNDS AND BLENDS

Initial studies were conducted using carbon wool as a filler material for various fluoroelastomers. These compounds also utilized high temperature secondary oven cures. As exemplified by compounds RAF-12, -13, -14, and -29, compression set characteristics in the range of 13 to 19% were achieved. However, little improvement in temperature retraction (TR-10) characteristics was obtained.

ECD-487 compounds displayed that their low temperature characteristics were superior to other forms of Viton. Unplasticized ECD-487 compounds, RAF-17, -29, -54, displayed TR-10 characteristics of approximately -20°F. Compound RAF-17 was subsequently molded into O-rings and evaluated in hydraulic testing, where it proved deficient in extrusion resistance. The deficiency in extrusion resistance was also established as characteristic of MIL-R-25897 compounds that were utilized as a standard against which experimental fluoroelastomeric compounds could be measured. Compound RAF-54 which utilized FEF black to enhance extrusion resistance was also subjected to hydraulic testing, and ultimately proved to be one of the most successful compounds developed. Trials subsequently undertaken to develop other more extrusion resistant fluoroelastomeric compounds culminated with compounds RAF-53, RAF-54 and RAF-55. These compounds basically used FEF black in conjunction with Viton B, ECD-487 and Viton A-HV, respectively. Evaluation of the three compounds in hydraulic tests established RAF-54 as having the best all-around sealing ability. The Viton A-HV compound exhibited the best compression set characteristics; however, the superior TR-10 properties of the ECD-487 apparently provided these O-rings with superior low temperature sealing capabilities.

Considerable effort was devoted to achieve improvement in the low temperature capability of commercially available fluoroelastomers by (1) the use of plasticizers and (2) reducing or eliminating the usual high temperature secondary curves which volatilize plasticizers. The resulting compounds characteristically lacked compression set resistance, although many attained good low temperature flexibility. The evaluations performed in this area by Republic indicate that a less volatile plasticizer would be an extremely valuable tool to the rubber compounder, and the search for such an agent might be the objective of a worthwhile program.

A study of available plasticizers was conducted using a Paracril 18-80 compound as an economical vehicle for comparison purposes. The results are listed in Table II.

As shown in Table II, the results were rather disappointing. However, Flexol GPE and -EPO were utilized in compounds RAF 91 through -94, -96 and -97. As anticipated little significant improvement was realized.

Attempts were made to blend fluoroelastomers with other polymers to attain superior properties. Table III describes some of these blends.

TABLE II - PLASTICIZER STUDY

Compound	Plasticizer	TR-10	Volume Change
RAN 61	TP-95	-46°F	+32%
RAN 67	Flexol GPE	-46°F	+25%
RAN 70	Halby LTR 268	-36°F	+31%
RAN 68	Flexol EPO	-36°F	+33%
RAN 69	Halby LTR 200	-38°F	+29%
RAN 71	TP110	-42°F	+27%
RAN 72	MT 511	-38°F	+30%
RAN 73	DC 3089	-34°F	+21%
RAN 74	DC 3090	-12°F	+23%

TABLE III - INGREDIENTS OF BLENDS

(parts by weight in parenthesis)

Compound		
RAF-21	Viton B (100)	G. E. SE-450 (Semi-cured) (50)
RAF-23	Viton AHV (50)	Dynagen XP139 (50)
RAF-25	Viton B (95)	Butyl HT1066 (5)
RAF-42, -43, -60, -67	Viton B (50)	Cyanacril LT 3 (50)
RAF-68, -69	Fluorel 2140 (85)	Cyanacril LT3 (15)
RAF-70, -81	Viton AHV (75)	Cyanacril LT3 (25)
RAF-71, -79, -80	Fluorel KX2150 (75)	Cyanacril LT3 (25)
RAF-92, -96, -97	Viton A (95)	Nordel 1070 (5)

Little significant improvement was attained by any of these combinations. In general, the poorer characteristics of each ingredient dominated the resulting compound or inhibited the attainment of good results.

2. EPICHLOROHYDRIN COMPOUNDS

The B. F. Goodrich Chemical Company has developed polymers based on epichlorohydrin. An epichlorohydrin polymer, designated as CHR rubber, did not offer sufficient low temperature flexibility as evidenced by compounds RAX-1 and RAX-13. However, a copolymer, now designated as Hydrin 200, offers good oil resistance, strength, and low temperature flexibility; but its compression set resistance and heat resistance appeared somewhat marginal. Unfortunately, the copolymer was so new that its availability was somewhat limited, thus the level of compounding effort it deserved could not be attained.

Compound RAK-3 offered sufficient promise to warrant hydraulic evaluation, and it proved to be an effective seal.

Cure trails with piperazine hexahydrate proved unsatisfactory, probably because an ineffective brand was utilized. This material is reported to provide low compression set, with somewhat inferior heat resistance.

Studies of the effects of secondary oven cures were conducted. Initial trials of 24 hours duration at 212°F did not prove particularly effective, as evidenced by compounds RAK-4 through RAK-8. However, later trials of 24 hours at 300°F produced compounds with compression set as low as 39% (RAK-26). The low elongation of this compound did not permit establishing its TR-10 value; however, it undoubtedly possessed good low temperature flexibility.

The Hydrin 200 copolymer appears to be tolerant of the type of black used since compounds exhibiting promising qualities were produced using SAF-, HAF-, FEF black, and combinations thereof.

Blends with Hydrin 200 were not tried and it is possible that some improvements may be obtained by this means. To date, most other blends have generally resulted in the poorer properties of each constituent.

It is doubtful that the ultimate in properties has yet been achieved, since any new polymer requires a great amount of work before it is properly exploited. The favorable results of work conducted so far is extremely encouraging and hopefully will provide a springboard for commercial compounds.

3. POLYACRYLATE COMPOUNDS AND BLENDS

The considerable interest focused on the polyacrylate polymers for use as automotive transmission seals has resulted in the development of many new polymers. Republic included these polymers in its investigation. The major objectives were to attain good low temperature flexibility coupled with sufficient strength to permit use as high pressure hydraulic seals. Ten plasticized Thiacril 55 compounds were developed, but in general lacked sufficient strength for high pressure work. Compound RAA-43 appears to offer the best all around qualities.

Several experimental Hycar polymers (Hycar 2121X58, -X60, and -X61) offered considerable promise. RAA-39, which used Hycar 2121X58 with ten parts of plasticizer, had properties which fell just short of the target goals. When it was learned that these polymers would not be produced commercially, emphasis was shifted to Hycar 2121X38, which the manufacturer does intend to produce. Unfortunately, this polymer had a tendency to swell more than the others, thus limiting its usefulness.

Five Hycar 4021 compounds were produced that were marginal in strength and compression set resistance when plasticized to achieve low temperature properties.

Thiacril 76 compounds showed considerable promise as evidenced by compounds RAA-49, -61, and -62. RAA-49 attained a modulus of 640 psi, TR-10 value of -30°F, compression set of 48% and generally displayed good heat and oil resistance.

A number of blends were attempted in an effort to impart low temperature properties to polyacrylates without extensive use of plasticizer. Table IV illustrates the combinations attempted.

TABLE IV - BLENDING INGREDIENTS

(parts by weight in parenthesis)

Compound		
RAA-6, -12	Thiacril 44 (75)	Butyl HT-1066 (25)
RAA-7	Cyanacril (75)	Butyl HT-1066 (25)
RAA-10	Cyanacril (85)	Butyl HT-1066 (15)
RAA-14	Thiacril 55 (85)	Butyl HT-1066 (15)
RAA-23	Cyanacril (50)	Paracril 18-80 (50)
RAA-25	Cyanacril (50)	Dynagen XP139 (50)
RAA-26	Cyanacril (85)	Nordel (15)
RAA-44, -47, -50	Thiacril 55 (66.6)	Cynacril LT3 (33.3)
RAA-45	Cyanacril (50)	Cyanacril LT3 (50)
RAA-51, -67	Hycar 4021 (80)	Cyanacril LT3 (20)
RAA-58	Hycar 2121X38 (66.6)	Cyanacril LT3 (33.3)
RAA-59	Thiacril 55 (75)	Cyanacril LT3 (25)
RAA-60	Thiacril 76 (80)	Cyanacril LT3 (20)

Cyanacril LT3, a polyacrylate elastomer reported to have good low temperature properties,was used extensively as a blending ingredient. While it appeared to be of some benefit in this respect, the swell characteristics of all resulting compounds,with the exception of RAA-60,suffered.

Blends of polyacrylate with chlorobutyl, or ethylene propylene, or propylene oxide rubber also produced compounds which swelled excessively.

Although the polyacrylates showed some promise of meeting the target goals, no compounds were developed with all the properties necessary to warrant hydraulic system testing. In the final phases of the program, work was discontinued in this area to permit major emphasis on the fluoroelastomers and epichlorohydrin elastomers.

4. BUTADIENE-ACRYLONITRILE COPOLYMERS AND BLENDS

Experiments relating to the cure system, use of non-black fillers, blending, and plasticizing were conducted on butadiene-acrylonitrile copolymers. The use of the resin cure (SP 1045 and SP 1055) in compounds RAN-32 through -38, -41, -45, and -46 did not impart any improvement in heat resistance and actually resulted in inferior resistance to compression set. A peroxide cure also failed to establish any distinct advantage. By utilizing magnesium oxides such as Maglite as fillers, compounds with good heat resistance such as RAN-60 were produced. This property could be further improved by the use of a less volatile plasticizer. However, it seemed unlikely that the resistance to compression set of such magnesia-filled compounds could be improved; consequently any improvement in their heat resistance would be of little benefit.

Blends with propylene oxide rubber (RAN-40 and -47)failed to produce a useful combination of properties.

Blends of Hycar 1042 and Ameripol CB resulted in inferior oil resistance without effecting any significant improvement in other properties.

Compounds RAN 67 through -74 were used in a plasticizer study which was discussed in Subsection II-1 - Fluoroelastomers.

The results obtained appear to confirm earlier assumptions that it is unlikely that the life of Buna N for 275°F service can be extended.

5. FLUOROSILICONE COMPOUNDS

The fluorosilicone elastomers, in general, have excellent oil resistance, heat resistance, and low temperature flexibility. Unfortunately, their resistance to wear is poor. Compound RAS-6 established that carbon wool can be of value in silicone compounds. The compression set of this compound was 29% in comparison to 49% for RAS-5, a similar compound which used Cab-O-Sil MS-7 for reinforcement. RAS-6 was subjected to O-ring testing and proved to have inadequate extrusion resistance. Utilizing carbon wool in combination with a more conventional filler in compound RAS-8, failed to impart superior strength to this fluorosilicone compound. In addition, the compression set resistance suffered. A recently developed polymer, Silastic LS-X-3033OU, exhibited an excellent combination of swell, compression set resistance, and low temperature flexibility; however, there was no indication that any significant improvement in strength had been achieved. Efforts with the silicone polymers were abandoned, because no approach towards achieving increased strength could be established.

Although the silicone compound does not presently appear applicable to MIL-P-5514 utilization of O-ring as a seal, future consideration could be given for seal application where strength is not of primary importance. Such an application might use a silicone O-ring in conjunction with a fluorocarbon "cap" seal. In this application the O-ring acts as a spring to energize the "cap," which does the actual sealing.

6. PROPYLENE OXIDE RUBBER COMPOUNDS AND BLENDS

The General Tire and Rubber Company recently announced a new experimental propylene oxide copolymer, "Dynagen XP-139." This elastomer was reported to have excellent low temperature flexibility, but with oil resistance somewhat poorer than Paracril 18-80. When compounded, Dynagen XP-139 proved to swell excessively when used with MIL-H-5606 oils. Blends with Hypalon 30 (RAQ-6, -8 and -10), Silastic LS63U (RAQ-4), and Viton A-HV (RAF-23) were attempted. Only in the silicone blend was the volume swell actually reduced to a near practical level; however, other properties were deficient. The good low temperature properties of propylene oxide rubber could not be transferred to a practical compound and work with this copolymer was then stopped.

7. POLYURETHANE COMPOUNDS AND BLENDS

Since it was known that millable polyurethane gums lack inherent resistance to compression set, emphasis was placed on attempts to correct this problem. Carbon wool was used as a filler in compound RAU-17; however, no improvement in compression set resistance resulted. Blends with silicone rubber (RAU-25 and -26) and Hypalon 20 (RAU-21 and -28) also failed to produce any improvement in this characteristic. Elastothane 455, Vibrathane 5004 Adiprene C, and Genthane SR were among the polymers surveyed before work with the polyurethanes was discontinued.

8. CHLOROSULFONATED POLYETHYLENE COMPOUNDS AND BLENDS

A blending study was conducted using chlorosulfonated polyethylene rubber with propylene oxide, ethylene propylene terpolymer, polyurethane, and polybutadiene (RAE-19 through -22). The latter three formulations showed rather good heat resistance, but they had poor compression set as well as an unacceptable combination of low temperature flexibility and volume change. Thus further work in this area was discontinued.

9. VINYL PYRIDINE COMPOUNDS AND BLENDS

Vinyl pyridine and vinyl pyridine-acrylonitrile polymers were evaluated in compounds RAX-9-10 and -11. Blends of the two were attempted in formulations RAX-12 and -15. These compounds did not offer sufficient heat resistance to warrant further efforts. The resin cure utilized an blend RAX-15 also failed to produce significant improvement.

10. MISCELLANEOUS COMPOUNDS

RAX-5 was the basis of an attempt to utilize a peroxide cure on an ethylene-vinyl acetate copolymer. The polymer did not have sufficient hot oil resistance to warrant further study.

In 1957 the Minnesota Mining and Manufacturing Company developed an elastomer described as a homopolymer of 3 perfluoromethoxy 1, 1 dihydroperfluoropropylacrylate. This polymer was developed under Air Force Contract AF33(038)-515 under the direction of the Air Force Materials Laboratory of the then Wright Air Development Center. Although no gum was available, test slabs for RAX-6 were provided by Minnesota Mining and Manufacturing Company. If gum were available, the 2F4 might have been good candidate elastomer by adapting more modern compounding techniques and by improving compression set with a secondary oven cure.

RAX-7 is the result of a preliminary compound of Nitroso rubber manufactured by the Thiokol Chemical Corporation. This is a copolymer described as trifluoronitroso-methane-tetrafluoroethylene. Its low temperature properties and oil resistance are excellent. Insufficient gum was available to perform temperature retraction tests or further compounding studies.

RAX-14 was compounded using Levapren 450, a type of ethylene vinyl acetate copolymer made in West Germany. This copolymer is reported to have excellent heat resistance and very low compression set. Its poor oil resistance and poor low temperature flexibility eliminated its usefulness to this program.

RAC-53 is a blend with a neoprene containing acrylonitrile. Its high compression set and volume swell eliminated it from further investigation.

SECTION III

O-RING EVALUATION

1. GENERAL

O-rings are used as seals under a wide variety of conditions in 3000 psi hydraulic systems using MIL-H-5606 fluids. According to use, the broadest subdivision is between static and dynamic seals. However, another important consideration in seal life is the extent to which the seal is exposed to air. Thus, four important classes of usage application emerge:

- Static seals which are completely submerged in oil (such as a static seal in a dam between oil chambers).
- Static seals which are exposed to oil on one side and air on the other (such as the static seals on pump heads, cylinder heads, etc.).
- Reciprocating dynamic seals which are completely submerged in oil (such as a piston head seal in an actuator).
- Reciprocating dynamic seals which are exposed to oil on one side and air on the other (such as a piston rod seal).

Other applications for O-rings such as oscillatory or rotary service do exist; however, their occurrence is relatively infrequent (and often troublesome) and, therefore, were not considered major performance criteria.

The program was aimed at fulfilling the intent of ARP-820 for long term O-ring service at +275°F while still retaining good low temperature sealing. This requirement coupled with the four aforementioned applications formed the basis for the performance test used in the program.

2. TEST PROCEDURE

a. Static Tests

These static tests were accomplished in a test cylinder depicted in Figures 1 and 2. The housings are made of 7075-T6 aluminum alloy to permit simulation of typical aircraft applications. Piston rods are made of chrome plated steel finished to 8-16 rms. O-ring cavities are identical to MIL-P-5514 grooves, with the exception that the diametral clearance was reduced to a nominal .0012 inch since backup rings were not used.

Aging of the O-rings at 275° was accomplished by placing the test cylinders in one quart jars filled with MIL-H-5606 oil. These cylinders were

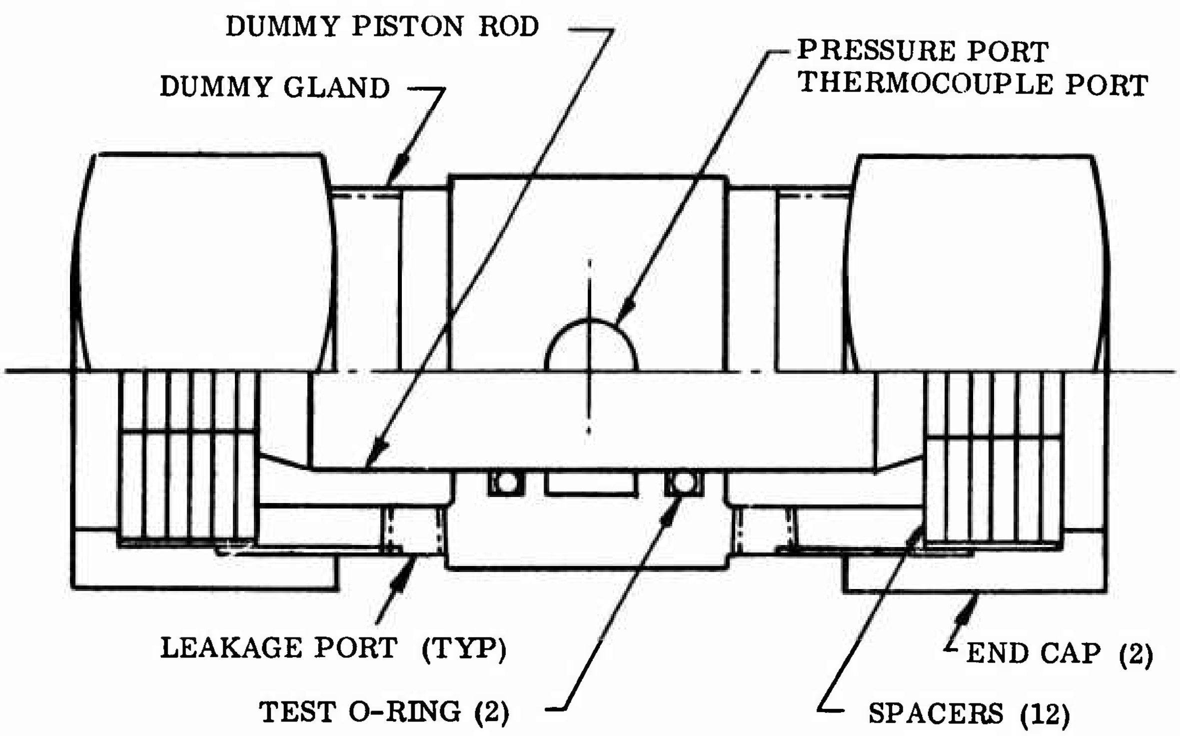


Figure 1. Static Test Cylinder - Drawing

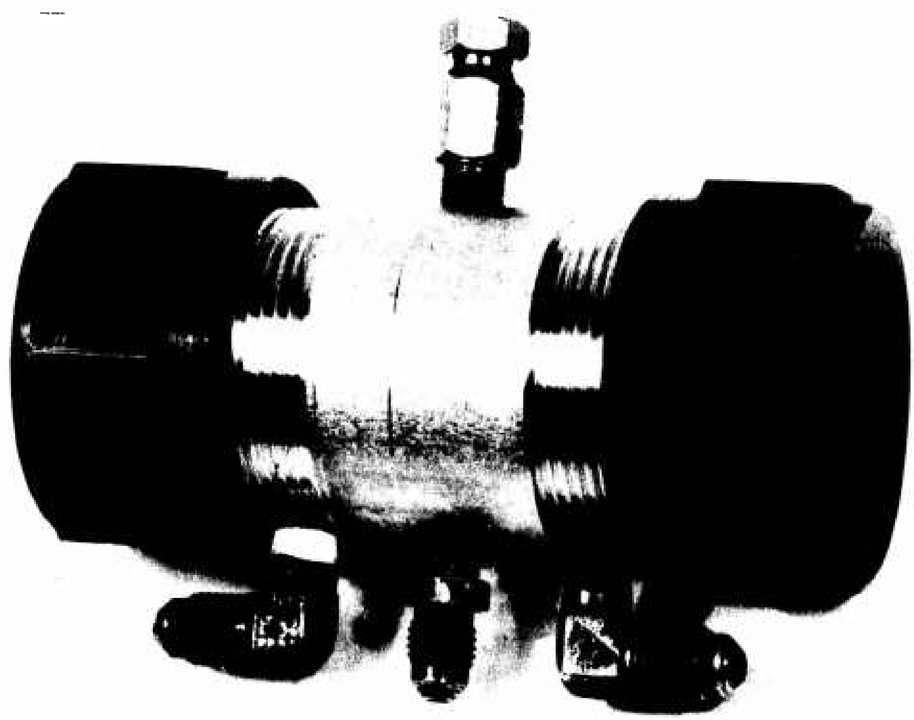


Figure 2. Static Test Cylinder - Hardware

then placed in a silicone oil bath which was maintained at 275° ± 4°F for 100 hour periods by automatic temperature controls and mechanical agitation of the fluid. Although the caps on the one quart jars were securely fastened, the level of the silicone oil bath was kept below that of the caps on the jars to preclude any possibility of fluids intermixing.

The test system for environmental control is shown in Figure 3. Cold temperatures were attained by a CO_2 system and high temperatures were obtained by heaters within the environmental chamber. A squirrel cage blower provide temperatures which were uniform to ±1° within the chamber. Pressure was obtained from a hydraulic power pack. Cycling from 0 to 3000 psi was accomplished by an attendant valving system. Figure 4 shows the test cylinders installed in the environmental system.

The test procedure is described below.

(1) Oil Aging Tests

(a) Soak packing in MIL-H-5606 oil at +275°F for 100 hours while installed in the test cylinder. Ensure that rings are completely surrounded by oil and no air pockets exist.

(b) Install test cylinder in static test system.

(c) Lower temperature to -30°F and stabilize, then leak check with 50 psi steady pressure for one hour.

(d) Reduce temperature to -65° and stabilize, then leak check with a 2-foot head of pressure for one hour.

(e) Initiate pressure cycling from 0 to -75 psi to 3000 psi at 30 ± 5 cycles per minute and initiate environmental heating. Accomplish temperature rise to +275°F within 40 minutes, and stabilize. Complete a total of 5000 pressure cycles.

(f) Remove rings from test fixture and check compression set and hardness. Check for evidence of extrusion.

(g) Repeat complete procedure until failure.

(2) Air-Aging Tests

(a) Install O-rings into static test cylinder. Connect air inlet line to pressure port. Connect air outlet line to thermocouple port. Submerge test fixture in MIL-H-5606 oil and age for 100 hours at 275°F. Insure that air is circulating through internal cavity during aging period by putting the air outlet line into an oil trap where a bubble rate of 60 bubbles per minute is visible.

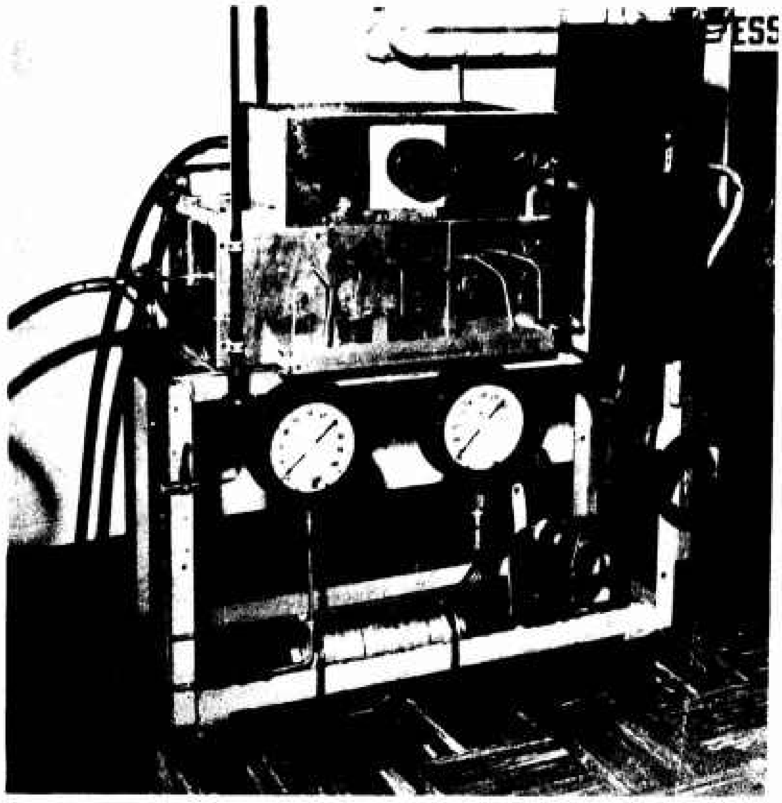


Figure 3. O-Ring Static Test System

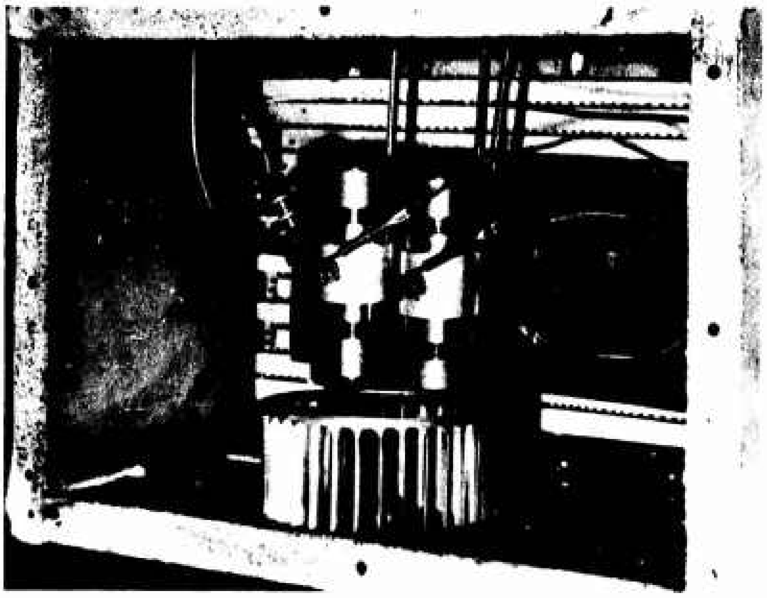


Figure 4. Static Test Cylinders Installed in Environmental Chamber

(b) At the conclusion of 100 hours of aging reverse the O-rings so that the side exposed to air during aging will now be exposed to air during pressure cycling.

(c) Install test cylinder in static test system.

(d) Lower temperature to -30°F and stabilize, then leak check with 50 psi steady pressure for one hour.

(e) Reduce temperature to -65° and stabilize, then leak check with a 2-foot head of pressure for one hour.

(f) Initiate pressure cycling from 0 to -75 psi to 3000 psi at 30 ± 5 cycles per minute and initiate environmental heating. Accomplish temperature rise to +275°F within 40 minutes, and stabilize. Complete a total of 5000 pressure cycles.

(g) Remove rings from test fixture and check compression set and hardness. Check for evidence of extrusion.

(h) Replace rings in static test cylinder so that the side exposed to air during aging will again be exposed to air during the next aging period. Note leakage throughout entire test.

(i) Repeat steps (a) through (h) until failure.

b. Dynamic Tests

Initially a test cylinder similar to that recommended in ARP-820 was selected for dynamic O-ring evaluations. This configuration uses the O-ring without backup rings. Instead it uses the O-ring with diametral clearances reduced to a minimum for 3000 psi service. A dynamic test cylinder for such service was designed and built (Figures 5 and 6). With the test cylinder universally mounted and mechanically driven by a varidrive and eccentric, shakedown runs were conducted (Figure 7). These runs utilized unaged MIL-P-25732 O-rings at room temperature to ensure that a ring with good physical properties could survive the test.

Problems initially encountered included excessive abrasion and rolling of the O-ring and wear on the gland. These problems were attributed to the short pitched grind pattern on the piston rod. Although the rod was checked to a 7 to -10 rms finish (well within MIL-P-5514 requirements) it was believed that the extremely short pitch of the grind pattern might have given a deceptive profilometer reading. Under microscopic inspection, the grind pattern appeared capable of filing the aluminum bearing land, thus generating particles that could abrade the O-ring, cause high local friction, and roll the ring. In an effort to eliminate this problem, the rod was lightly lapped. Refinishing the rod provided some reduction in the quantity of aluminum generated by wear on the bearings, and attendant abrasion of the specimen O-rings. However, the

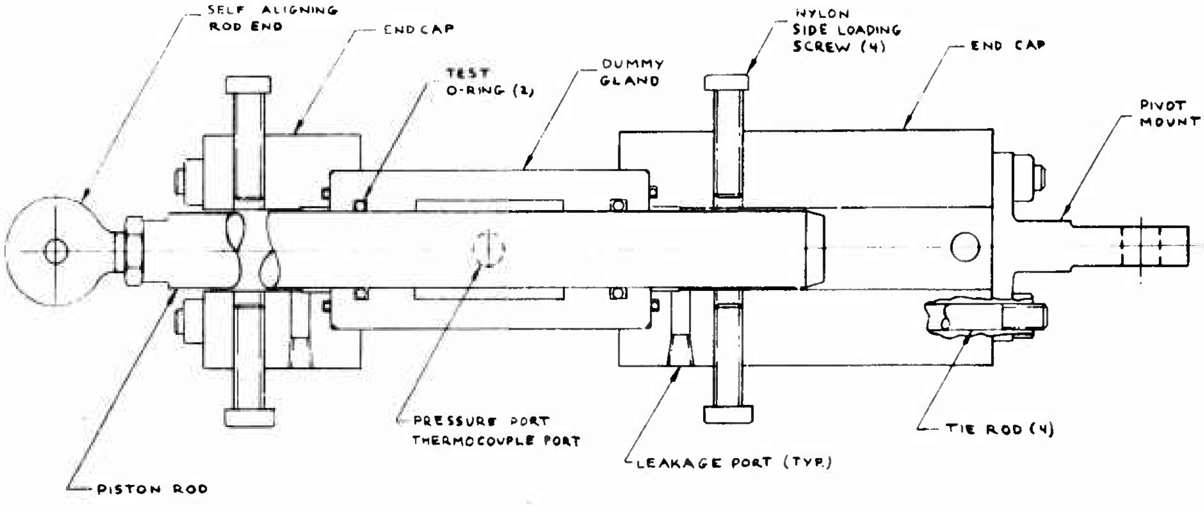


Figure 5. Initial Dynamic Test Cylinder - Drawing

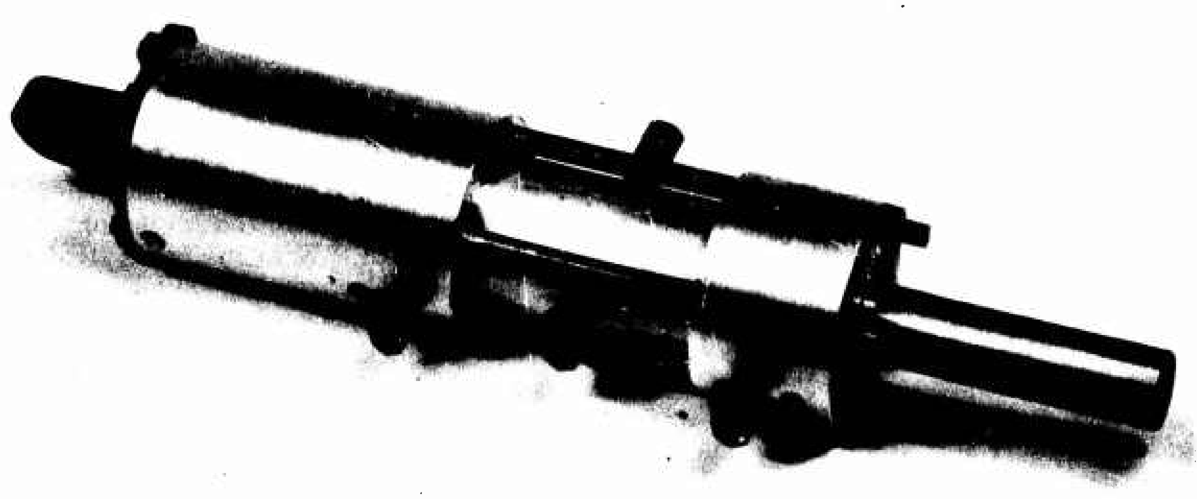


Figure 6. Dynamic Test Cylinder - Hardware

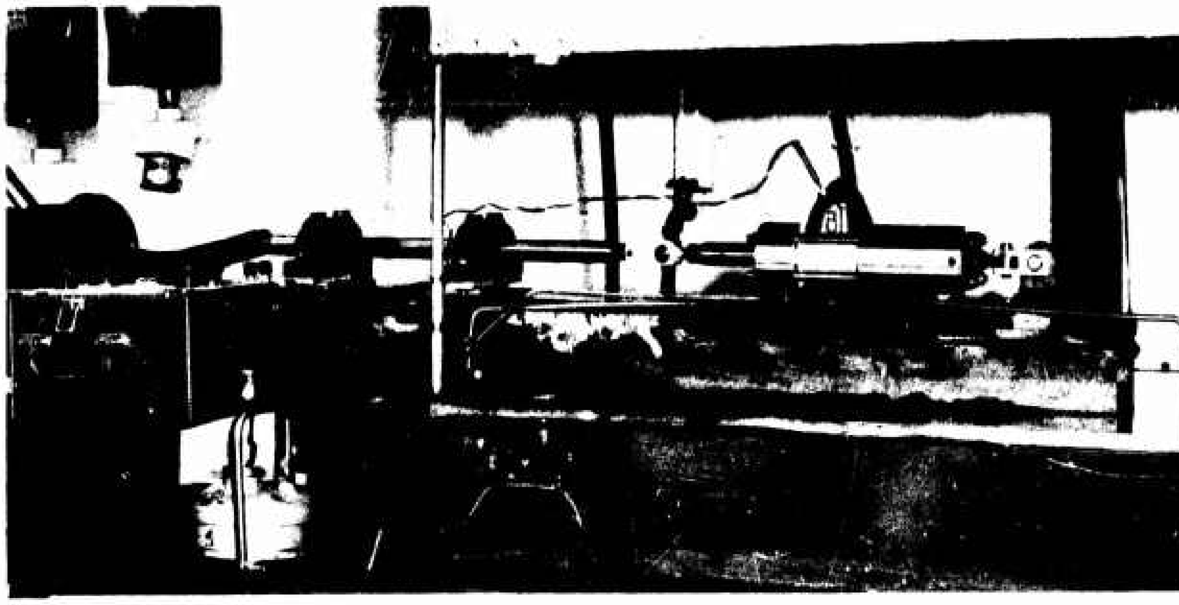


Figure 7. Initial Dynamic Test Cylinder - Mounted in Oven

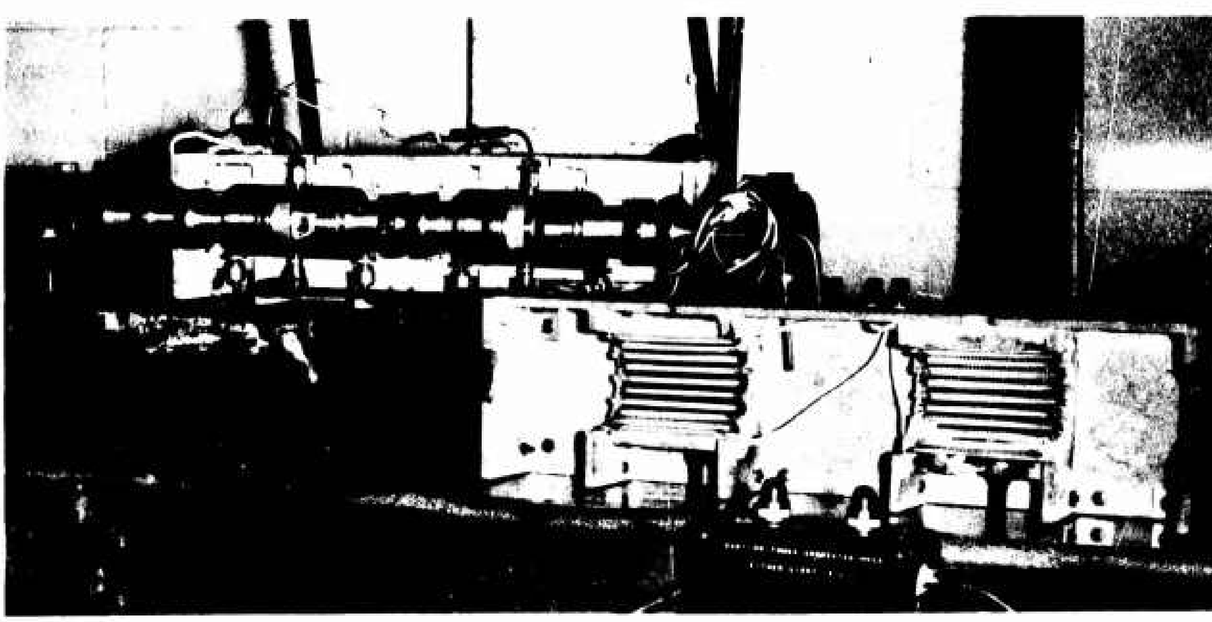


Figure 8. Dynamic Test Cylinder - Pillow Block Mounted

resulting conditions were still considered too severe to be realistic. In order to reduce the bearing load on the fixtures, the piston rod was mounted on two pillow blocks, with the housing mounted on the rod between the pillow blocks (Figure 8). This also failed to remedy the problem, since the rings continued to display excessive abrasion. It was then thought that the close diametral clearance (0.0015 inch) between the piston rod and bore might permit the generated aluminum particles to become wedged in the clearance space where they could score the bore and rod and abrade the O-ring.

The diametral clearance of one of the test cylinders was opened to MIL-P-5514 upper limits (0.006 inch) and dynamic tests were conducted at 1500 psi for 5000 cycles. The results seemed to offer promise. Abrasion appeared negligible, and no extrusion problems arose. In view of these results, the test was repeated at 3000 psi. Again, the results appeared good after 5000 cycles. However, after an additional 10,000 cycles, one of the rings was severely rolled, and had peeled where it had apparently been pinched in the diametral clearances and subsequently rolled.

At this stage of the investigation, it was believed that for 3000 psi service the use of backup rings in conjunction with the O-ring is necessary to provide an accurate estimate of the abrasion resistance of the rubber compounds being examined. Therefore, the O-ring cavities of one test cylinder were machined to accommodate backup rings. The test configuration now utilized MS 28774 rings in conjunction with the specimen O-ring. Correspondingly, the diametral clearances have been opened up to within .001 inch of the maximum allowable under MIL-P-5514. All other cavity dimensions conform to MIL-P-5514. This configuration was evaluated by utilizing a MIL-P-25732 compound O-ring which had not been subjected to heat-aging to 50,000 cycles, (4-inch stroke) at 275°F. No leakage resulted. The minor abrasion evident at the sealing surfaces of the rings at the conclusion of the run appeared commensurate with the number of dynamic cycles. The good material properties of the unaged Buna N easily compensated to produce an effective seal. The gland bearings showed negligible wear. The rings showed an average compression set of 57% (measured immediately after removal from the gland) at the conclusion of 50,000 cycles. The total time of exposure to 275°F was 25 hours, including testing, warmup, and shutdown. This dynamic test profile was then adopted for realistic evaluation of heat-aged compounds.

The test cylinders were modified to incorporate a two-piece MIL-P-5514 cavity, as shown in Figure 9. This was done so that diametral clearances could be kept consistent throughout testing. Inserts were replaced when they wore out of tolerance.

New backup rings were used prior to each 5000 dynamic cycles, because in many instances by extruding severely the MS 28774 proved marginal or deficient supporting the O-ring. Therefore, backup ring deterioration could have penalized O-ring performance and confused the results.

The oil- and air-aging oil bath used for dynamic O-rings was identical to that used for aging static specimens.

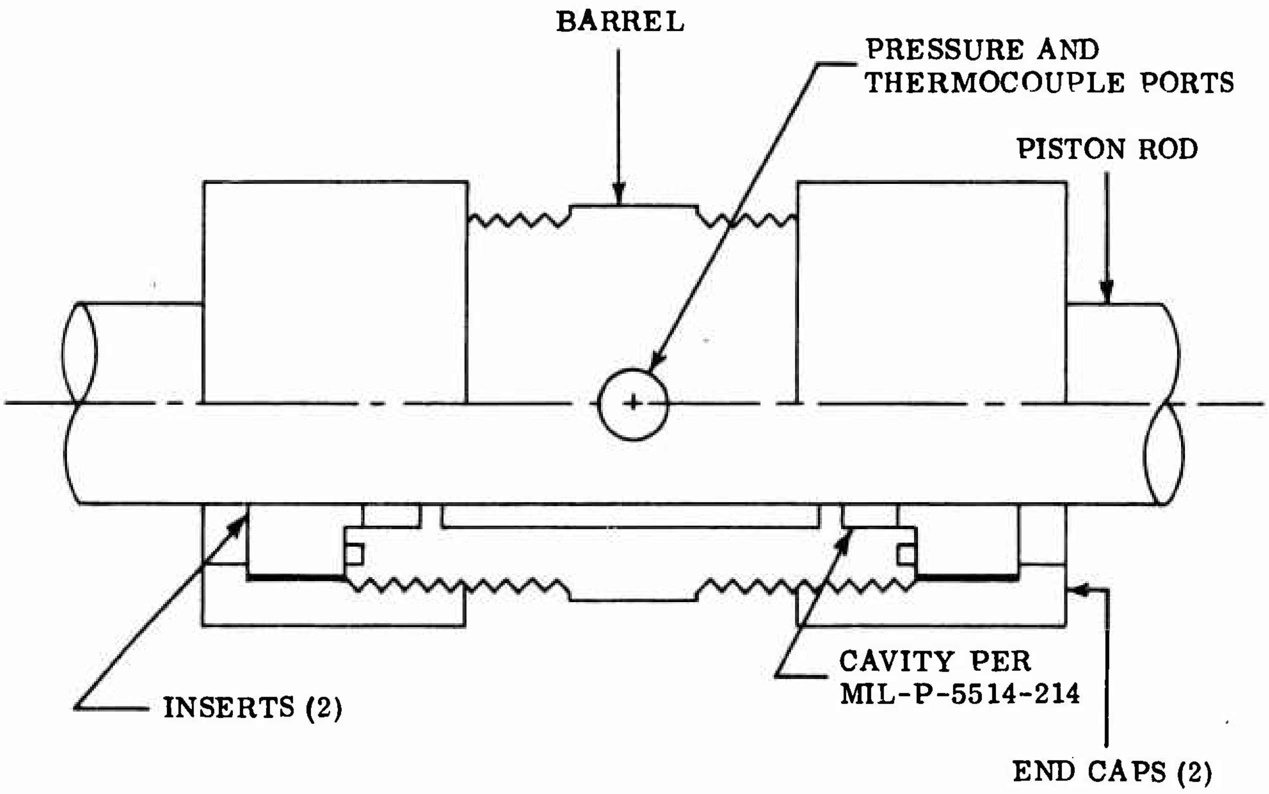


Figure 9. Dynamic Test Cylinder

The dynamic cycling system utilized a varidrive and eccentric as previously mentioned. Pressure during cycling was obtained from a hydraulic power pack. Environmental control was obtained from clamshell heaters which surrounded the test cylinders and permitted two dynamic cylinders to be tested concurrently.

The detailed test procedure used throughout the dynamic tests is described below.

(1) Oil-Aging Tests

(a) Soak packings in MIL-H-5606 oil at +275°F for 100 hours while installed in test cylinder without backup rings.

(b) Install test cylinder in environmental chamber.

(c) Reduce temperature to -30°F and stabilize, then leak check with 50 psi steady pressure for one hour.

(d) Reduce temperature to -65°F and stabilize, then leak check with a 2-foot head of pressure for one hour.

(e) Raise temperature to 275°F within one hour while maintaining 2-foot head. At 275°F raise pressure to 50 psi and maintain for 30 minutes. Allow cylinder to cool to room temperature.

(f) Install new MS 28774 rings on each side of specimen O-ring.

(g) Install test cylinder in dynamic test fixture.

(h) Apply 3000 psi continuous pressure and initiate 4-inch stroke cycling at 30 cycles per minute. Initiate environmental heating and effect temperature rise to +275°F within 45 minutes after cycling started. Complete 5000 cycles.

(i) Remove rings from test fixture and check compression set and hardness. Check for evidence of abrasion or extrusion. Note leakage throughout entire test.

(j) Repeat procedures (a) through (i) until failure.

(2) Air-Aging Tests

(a) Install O-rings into dynamic test fixture without backup rings. Connect air-inlet line to pressure port. Connect air outlet line to thermocouple port. Submerge test fixture in MIL-H-5606 oil and age for 100 hours at 275°F. Ensure that air is circulating through internal cavity during aging period by putting the air outlet line in an oil trap where a bubble rate of 60 bubbles a minute are visible.

(b) At the conclusion of 100 hours of aging reverse the rings so that the side exposed to air during aging will now be exposed to air during low temperature tests and dynamic cycling.

(c) Reduce temperature to -30°F and stabilize, then leak check with 50 psi steady pressure for one hour.

(d) Reduce temperature to -65°F and stabilize, then leak check with a 2-foot head of pressure for one hour.

(e) Raise temperature to 275°F within one hour while maintaining 2-foot head. When temperature is 275°F raise pressure to 50 psi and maintain for 30 minutes. Allow cylinder to cool to room temperature.

(f) Install new MS 28774 backup rings on each side of specimen O-ring.

(g) Install test cylinder in dynamic test fixture.

(h) Apply 3000 psi continuous pressure and initiate 4-inch total stroke cycling at 30 cycles per minute. Initiate environmental heating and effect temperature rise to +275°F within 45 minutes after cycling started. Complete 5000 cycles.

(i) Remove rings from test fixture and check compression set and hardness. Check for evidence of abrasion or extrusion. Note leakage throughout entire test.

(j) Repeat procedures (a) through (i) until failure.

3. TEST RESULTS

Initially MIL-P-25732 (butadiene-acrylonitrile) compounds and MIL-R-25897 (fluoroelastomeric) compounds were evaluated from two qualified sources, indicated as source "A" and source "B" in this report. O-rings made from these compounds were evaluated under the static and dynamic tests previously described to establish a performance standard against which experimental compounds could be measured. As promising experimental compounds emerged they were tested identically to the MIL specification compounds.

Failure was considered to have occurred when the cumulative leakage of both seals in the test cylinder exceeded 100 drops during any single low temperature and 5000 cycle phase of the complete test.

a. MIL-P-25732 Compounds

(1) Static Tests Oil-Aged

Source "A" compound MIL-P-25732 failed at the conclusion of 900 hours of heat-aging at 275°F in MIL-H-5606 oil. The ring in the "B" end of the test cylinder cracked during removal from the cavity. Up to this point the "B" end ring had displayed no leakage. The "A" end exhibited slight seepage at the conclusion of the 100-, 400-, and 700-hour soaks during impulse testing while the temperature was rising from -65°F to +275°F. The crack in the "B" end ring is shown in Figure 10.

Source "B" compound MIL-P-25732 failed after 500 hours at 275°F. Both rings broke during removal from the test fixture. Up to that point they had exhibited only minor extrusion and zero leakage during the tests. The durometer reading had increased to 82 at the conclusion of 500 hours at temperature. Figure 11 shows the condition of the ring at the conclusion of the test.

(2) Static Tests - Air-Aged

Source "A" compound MIL-P-25732 failed at the conclusion of 300 hours of aging at 275°F. Heavy leakage was noted from both the "A" and "B"

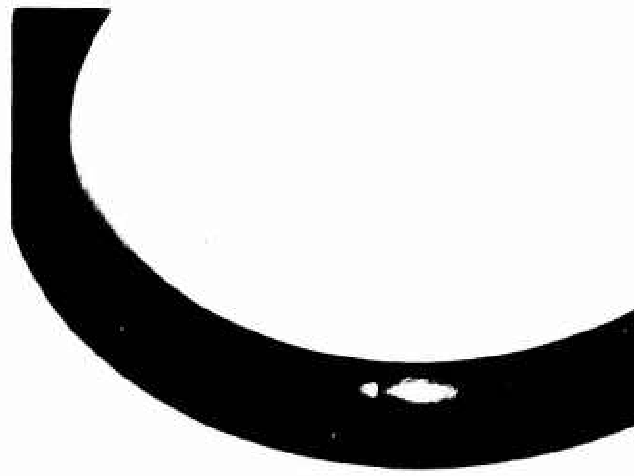


Figure 10. Source "A" - MIL-P-25732 O-Rings Tested Statically - Oil-Aged

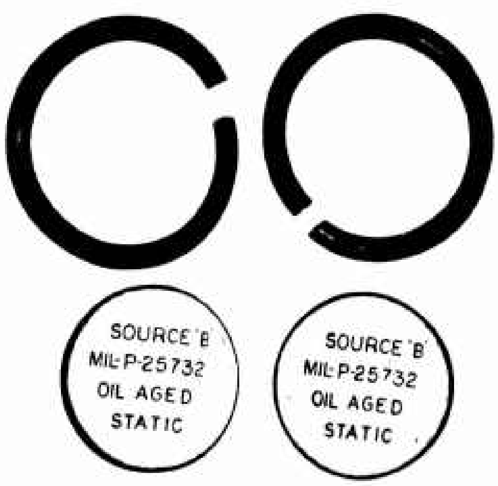


Figure 11. Source "B" - MIL-P-25732 O-Rings Tested Statically - Oil-Aged

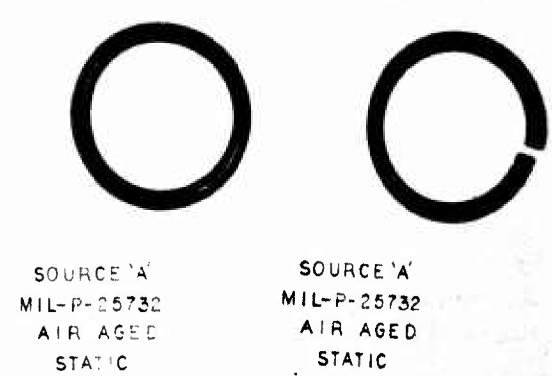


Figure 12. Source "A" - MIL-P-25732 O-Rings Tested Statically - Air-Aged

ends of the gland during impulse testing, while the temperature was rising from -65°F to +275°F. This leakage continued at 275°F, and the test was terminated. No leakage had been experienced at either -30°F or -65°F. The "B" end ring broke while being removed from the cavity for inspection. Durometer readings had reached 79/89 (air side of ring) at the conclusion of 300 hours of aging. These rings are shown in Figure 12.

Source "B" compound MIL-P-25732 failed at the conclusion of 300 hours of testing at 275°F. The ring cracked during removal from the cavity. The durometer reading rose to 89 on the air side of the ring, while remaining at 74 on the oil side. Figure 13 shows the condition of the ring at the conclusion of the test.

(3) Dynamic Tests - Oil-Aged

Source "A" MIL-P-25732 failed at the conclusion of 400 hours; source "B" failed at the conclusion of 500 hours. In both cases, compression set had reached approximately 78%. Several abrasion marks on the sealing surface of the "A" end of the source "A" ring (Figure 14) were responsible for its failure. The source "B" rings also showed some abrasion plus a tear along the seam of the "B" end ring (Figure 15).

(4) Dynamic Tests - Air-Aged

Source "A" and "B" compound MIL-P-25732 failed during dynamic cycling at the conclusion of 200 hours of air-aging at 275°F. Compression set in excess of 90% had occurred on all rings. Failure resulted from gland wear, which generated particles that subsequently abraded both the O-ring (Figures 16 and 17) and the backup ring. The backup ring was extruded and abraded.

b. MIL-R-25897 Compounds

(1) Static - Oil-Aged

Source "A" compound MIL-R-25897 failed during impulse testing at the conclusion of 100 hours soak. Although these O-rings survived low temperature testing at -30°F and -65°F, excessive leakage was noted during the temperature rise to +275°. Both rings displayed excessive chewing. No significant change in hardness was noted. The extrusion of the "A" end ring is shown in Figure 18.

Source "B" compound MIL-R-25897 failed after 200 hours of oil aging during the second impulse pressure test. Excessive leakage was noted at -30°F at 50 psi static pressure, and at 275°F during and after impulse cycling. These rings had displayed excessive extrusion after the first 100 hour soak and impulse cycle. Compression set had reached 85% average after 200 hours. No significant change in hardness was noted. Figure 19 shows the extensive chew on the "B" end ring.

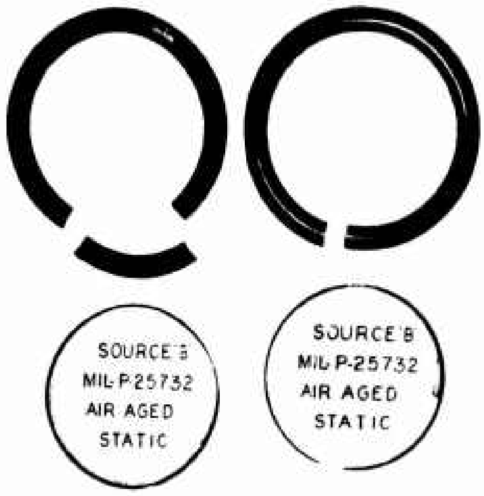


Figure 13. Source "B" - MIL-P-25732
O-Rings Tested Statically -
Air-Aged

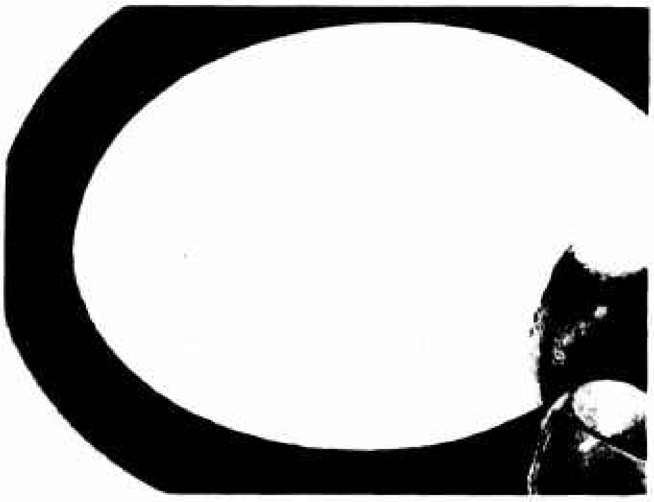
Figure 14. Source "A" - MIL-P-25732
O-Rings Tested Dynamically -
Oil-Aged

Figure 15. Source "B" - MIL-P-25732
O-Rings Tested Dynamically -
Oil-Aged

Figure 16. Source "A" -MIL-P-25732 O-Rings Tested Dynamically Air-Aged

Figure 17. Source "B" - MIL-P-25732 O-Rings Tested Dynamically - Air-Aged

Figure 18. Source "A" - MIL-R-25897 O-Rings Tested Statically - Oil-Aged



(2) Static - Air-Aged

Source "A" compound MIL-R-25897 was considered to have failed at the conclusion of 200 hours of heat-aging with air on one side of the ring. Heavy leakage was experienced during impulse cycling, and the rings displayed heavy nibbling. Figure 20 shows the nibbling and the debris. Compression set had reached approximately 78% at this point.

Source "B" compound MIL-R-25897 failed after 100 hours of aging at 275°F with one side of the ring exposed to fluid and the other side exposed to air. No leakage was noted at -30°F or -65°F. However, after warm-up to +275°F, leakage was noted from both rings. At the conclusion of 5000 pressure cycles, both rings were severely extruded, as shown in Figure 21.

(3) Dynamic - Oil-Aged

Source "A" compound MIL-R-25897 was considered to have failed at the conclusion of 500 hours of oil aging at 275°F and 25,000 dynamic cycles. Excessive leakage was noted during the last cold temperature check. Compression set had reached approximately 80% and bearing wear had taken place. These rings generally appeared in good condition, as shown in Figure 22.

Source "B" MIL-R-25897 O-rings were considered to have failed at the conclusion of 400 hours of oil aging at 275°F and 20,000 dynamic cycles. Leakage had been increasing progressively since the 200-hour mark. Compression set (75%) of the rings permitted wear to occur on the bearing, thus generating metallic particles. These particles increased the abrasion taking place on the O-rings. Several deep abrasion scars were evident on the dynamic sealing surface. One of these scars is shown in Figure 23.
in Figure 23.

(4) Dynamic - Air-Aged

Both the source "A" and "B" compound MIL-R-25897 failed at the conclusion of 100 hours of air aging and 500 dynamic stroke cycles. In both cases, the failure followed the same pattern; the backup ring proved marginal, wearing and extruding into the diametral clearance gap. This permitted local nibbling to occur, thus providing a leakage path. These O-rings are shown in Figures 24 and 25.

c. Experimental Compound RAF-17

(1) Static - Oil-Aged

O-rings made from experimental ECD-487 compound RAF-17 failed after the first 100-hour soak. Failure occurred after 2000 pressure impulse cycles. The ring was severely extruded, indicating the need for further reinforcement in this compound. This condition is shown in Figure 26. No further testing was conducted on this compound.

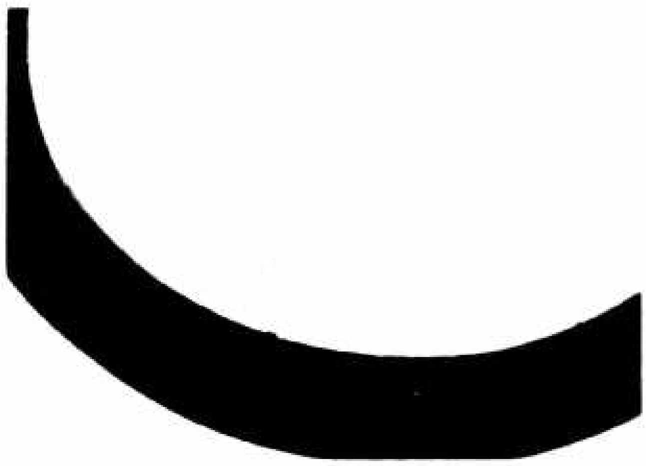
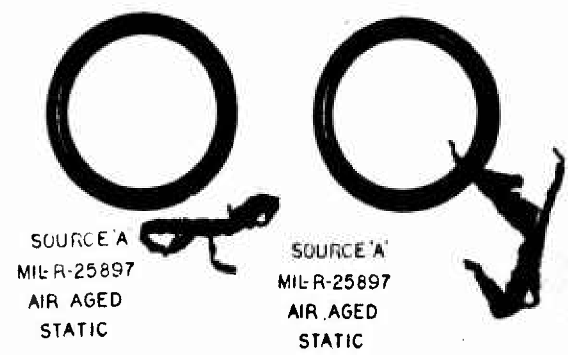


Figure 19. Source "B" - MIL-R-25897 O-Rings Tested Statically - Oil-Aged

Figure 20. Source "A" - MIL-R-25897 O-Rings Tested Statically - Air-Aged



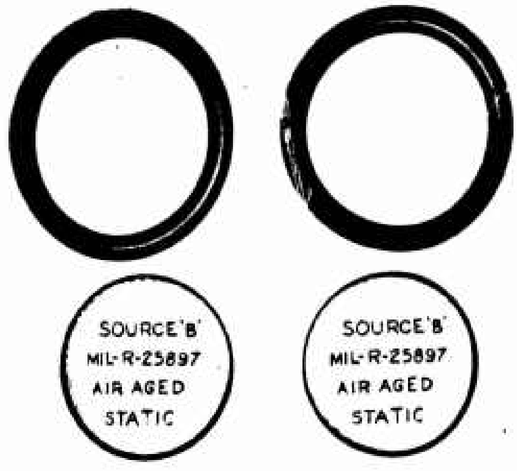
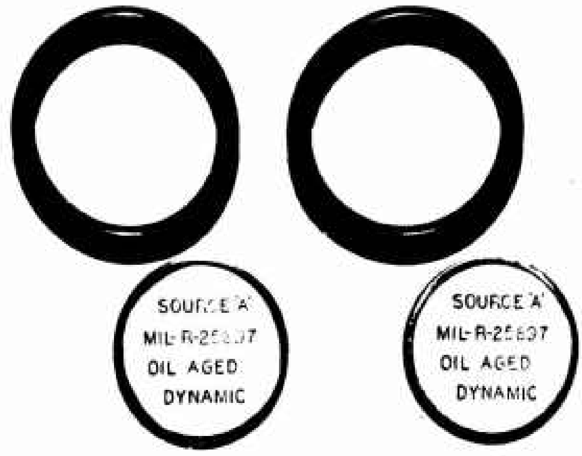


Figure 21. Source "B" MIL-R-25897 O-Rings Tested Statically - Air Aged

Figure 22. Source "A" - MIL-R-25897 O-Rings Tested Dynamically - Oil-Aged



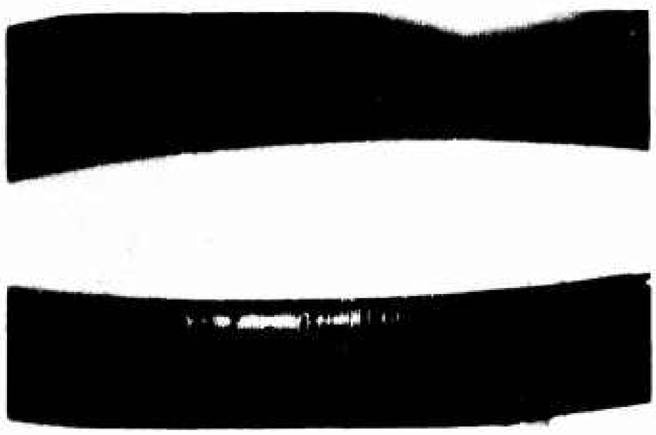
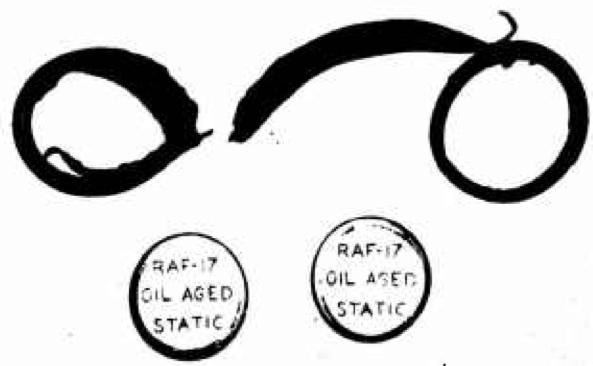


Figure 23. Source "B" - MIL-R-25897 O-Rings Tested Dynamically - Oil-Aged

Figure 24. Source "A" - MIL-R-25897 O-Rings Tested Dynamically - Air-Aged

Figure 25. Source "B" - MIL-R-25897 O-Rings Tested Dynamically - Air-Aged

Figure 26. Compound RAF-17 O-Rings Tested Statically - Oil-Aged



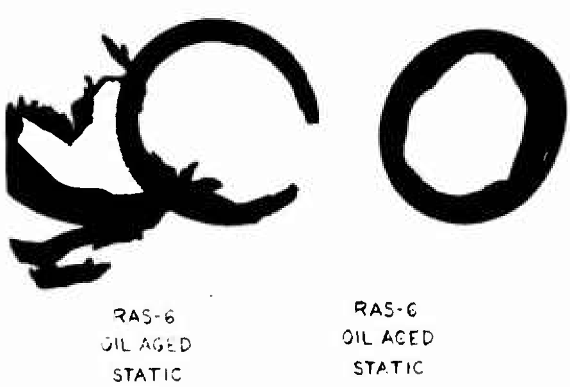


Figure 27. Compound RAS-6 O-Rings Tested Statically - Oil-Aged

d. Experimental Compound RAS-6

Rings molded from experimental fluorosilicone compound RAS-6 also failed after the first 100 hours of oil aging. Failure due to severe extrusion occurred during impulse cycling. As in the case of the RAF-17 O-rings, further reinforcement is necessary. These rings are shown in Figure 27. No further testing was conducted on these rings.

e. Experimental Compounds RAF-53 and RAF-55

(1) Static Tests - Oil-Aged

Experimental fluoroelastomeric compounds RAF-53 (Viton B base) and RAF-55 (Viton A-HV base) were considered to have failed at the conclusion of 400 hours of oil aging at 275°F and 20,000 pressure impulse cycles. In both cases, excessive leakage occurred during the rise from low to high temperature. RAF-53 had reached a compression set of 77%; the RAF-55 compound had reached only 63% compression set. The relatively small amount of extrusion on these rings is shown in Figures 28 and 29. Further testing of these rings was discontinued in favor of compound RAF-54, which displayed superior performance in this test. All three compounds, RAF-53, RAF-54, and RAF-55, were the result of reinforcement studies which were initiated to make the fluoroelastomers more extrusion resistant.

f. Experimental Compound RAF-54

(1) Static Test - Oil-Aged

Fluoroelastomeric compound RAF-54 (ECD 487 HV, Lot B base) failed during pressure impulse cycling at the conclusion of 600 hours of oil aging at 275°F. Failure was attributed to deep extrusion in the "A" end O-ring as shown in Figure 30. Compression set had reached 77% at the conclusion of 600 hours of oil aging.

(2) Static Test - Air-Aged

Air aging tests of ECD-487 compound RAF-54 have reached the 1000 hour mark. Fifty thousand static pressure impulse cycles and associated low temperature tests have been completed. Compression set reached 81% and the durometer reading was 77 at the conclusion of the test. These rings are shown in Figure 31.

(3) Dynamic - Oil-Aged

Oil aged compound RAF-54 O-rings failed at the conclusion of 400 hours of oil aging and 20,000 dynamic stroke cycles. Failure at the "B" end seal resulted from a tear about 1/4-inch long, as shown in Figure 32 which started along the seam of the inside diameter of the ring, and then extended slightly outward. The "A" end seal continued to seal effectively; however, a slight indentation was evident along the inside diameter of the seal.

Figure 28. Compound RAF-53 O-Rings Tested Statically - Oil-Aged

Figure 29. Compound RAF-55 O-Rings Tested Statically - Oil-Aged

Figure 30. Compound RAF-54 O-Rings Tested Statically - Oil-Aged

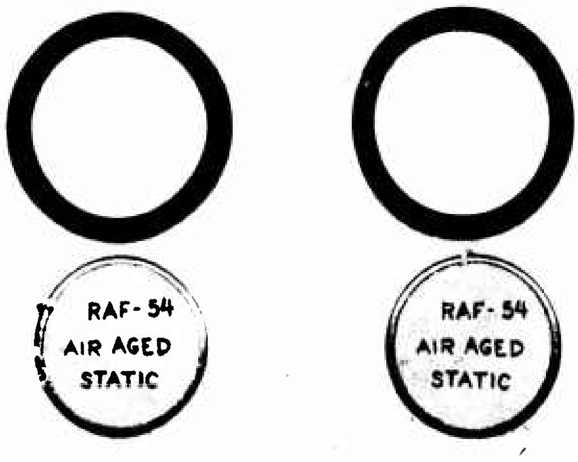


Figure 31. Compound RAF-54 O-Rings Tested Statically - Air-Aged

Figure 32. Compound RAF-54 O-Rings Tested Dynamically - Oil-Aged

Figure 33. Compound RAF-54 O-Rings Tested Dynamically - Air-Aged

(4) Dynamic - Air-Aged

Figure 33 shows air-aged RAF-54 O-rings which failed at the conclusion of 500 hours of air aging at 275°F and 25,000 dynamic stroke cycles. Excessive leakage was noted from the "B" end of the gland, although the ring appeared in good condition, and compression set was 71%. The "A" end seal exhibited a shallow tear 1/4-inch long on the dynamic sealing diameter. (See Figure 33.)

g. Experimental Compound RAK-3

(1) Static Tests - Oil-Aged

Hydrin 200 compound RAK-3 completed 1000 hours of oil aging at 275°F and 50,000 static pressure impulse cycles and associated low temperature tests (Figure 34). Compression set has reached 89% at the conclusion of 1000 hours, and the durometer reading was 79.

(2) Static Tests - Air-Aged

O-rings formulated from compound RAK-3 failed at the conclusion of 700 hours of air aging at 275°F and 34,000 pressure impulse cycles. Excessive leakage occurred steadily, at this time. Severe nibbling had occurred in the "B" end ring. The compression set of both rings had attained 88%. The durometer reading, which was 81 originally, had dropped to 76 in the "B" end ring and 79 in the "A" end ring. These rings are shown in Figure 35.

(3) Dynamic Tests - Oil-Aged

Oil-aged compound RAK-3 O-rings were considered to have failed at the conclusion of 700 hours at 275°F and 35,000 dynamic stroke cycles and associated low temperature checks. Heavy compression set coupled with abrasion in the sealing surface permitted excessive leakage to occur. The durometer readings dropped to 71 on the "B" ring and 75 on the "A" ring. Other properties had probably dropped appreciably since the durometer indenter marks remained on the surface of the ring, as shown in Figure 36.

(4) Dynamic Tests - Air-Aged

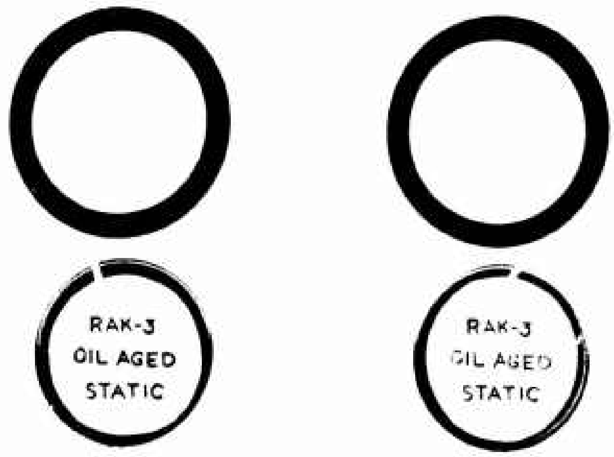
Compound RAK-3 O-rings were considered to have failed at the conclusion of 600 hours of air aging at 275° and 30,000 dynamic stroke cycles. Excessive leakage, apparently due to extensive compression set coupled with abrasion marks (Figure 37) on the sealing surface, was experienced during the last 5000 dynamic cycles.

A chart, Figure 38 summarizes the leakage, compression set characteristics, and performance life of all the compounds tested.

h. Long Term Compression Set Tests

One thousand-hour oil-aged tests in a MIL-P-5514 cavity without intermittent impulse cycling were conducted on a MIL-R-25897 compound, RAF-17, an

Figure 34. Compound RAK-3 O-Rings Tested Statically - Oil-Aged



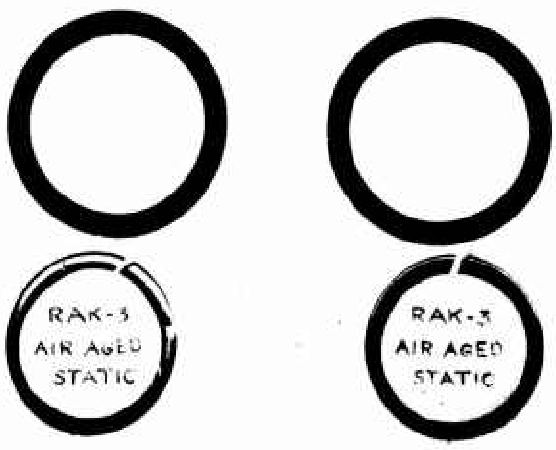
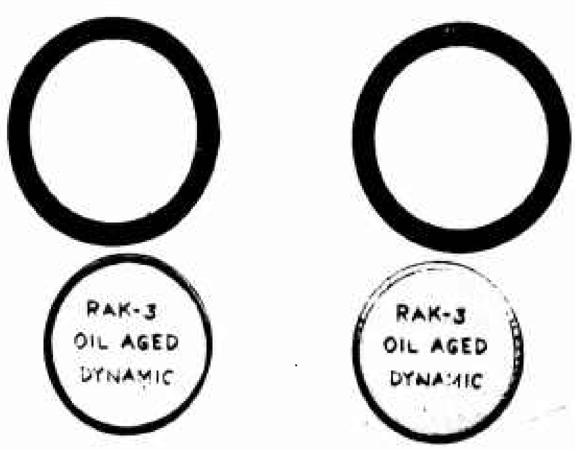


Figure 35. Compound RAK-3 O-Rings Tested Statically - Air-Aged

Figure 36. Compound RAK-3 O-Rings Tested Dynamically - Oil-Aged



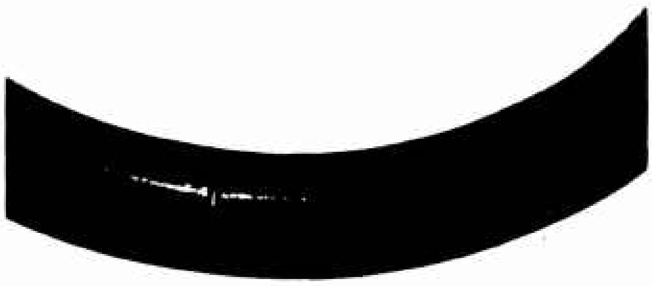


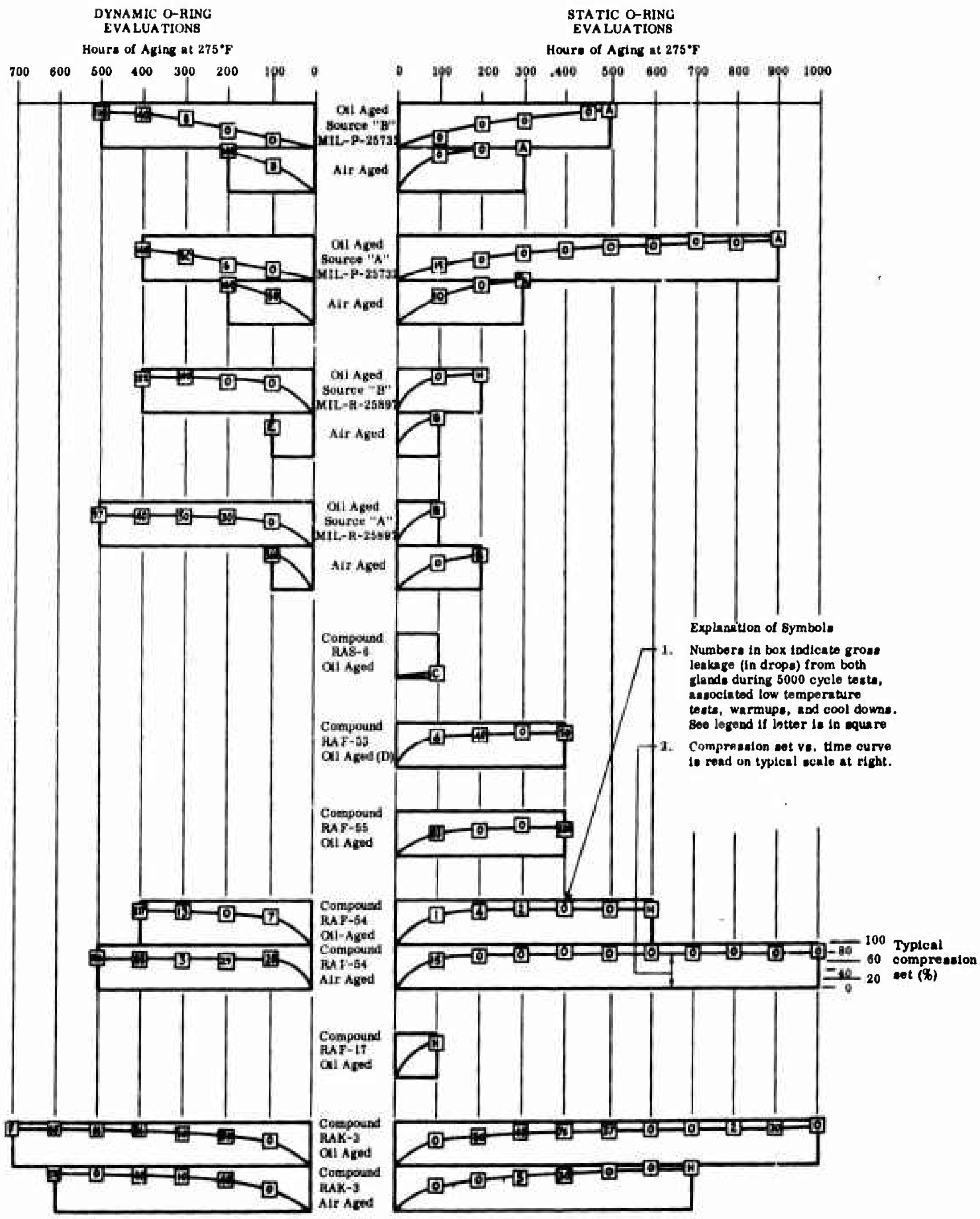
Figure 37. Compound RAK-3 O-Rings Tested Dynamically - Air-Aged

ECD-487 compound, and RAK-4 (a Hydrin 200 compound), with a 212°F secondary cure. Data for compound RAK-3 was taken from the impulse tests. The data does not indicate any clear advantage for any of the compounds past the 400 hour mark. The condition of the RAK-4 ring was extremely poor at the conclusion of 1000 hours. Its durometer reading had dropped to 52 on one of the rings, 68 on the other. Many cracks were evident on both rings. The RAK-3 rings although enduring static impulse tests were in better condition with a durometer reading of 79. Both the RAF-17 and the MIL-R-25897 rings appeared in good condition with negligible change in durometer reading (refer to Figure 39).

i. Backup Rings

MS28774 backup rings, which were used in the dynamic O-ring tests, have displayed poor performance. Figure 40 depicts the typical condition of four backup rings after 5000-dynamic cycles. Specifically, the figure shows how the rings extruded easily into the diametral clearance gap, and often fail to support the O-ring. For this reason new MS28774 backup rings were then used prior to each 5000-dynamic stroke cycle.

Contract N156-41574 reported the development of an improved backup ring. This ring was fabricated from a reinforced Teflon compound produced by the Dixon Corporation, Bristol, Rhode Island. In addition to the material change, minor alterations were made in the geometry of the ring. Since the intent of AF33(615)-1668 is to produce a better sealing system for 3000 psi Type II hydraulic systems, it appeared that the evaluation of O-ring performance



Legend:

A Ring cracked during removal from gland

B Leakage moderate, however, the ring was chewed over its entire sealing surface. Rubber particles in the diametrical clearance gap inhibited massive leakage.

C Complete failure of ring due to extrusion

(D) Leakage valves given for one ring only. "B" end O-ring was established to be in an improper state of cure.

E Heavy seepage throughout all low temperature tests. Exact leakage not recorded.

F Durometer dropped to 66. Many small cracks similar to "flex cracks" evident. Ring not tested dynamically after last aging period.

H Heavy leakage

Figure 38. Summary Chart of O-Ring Performance

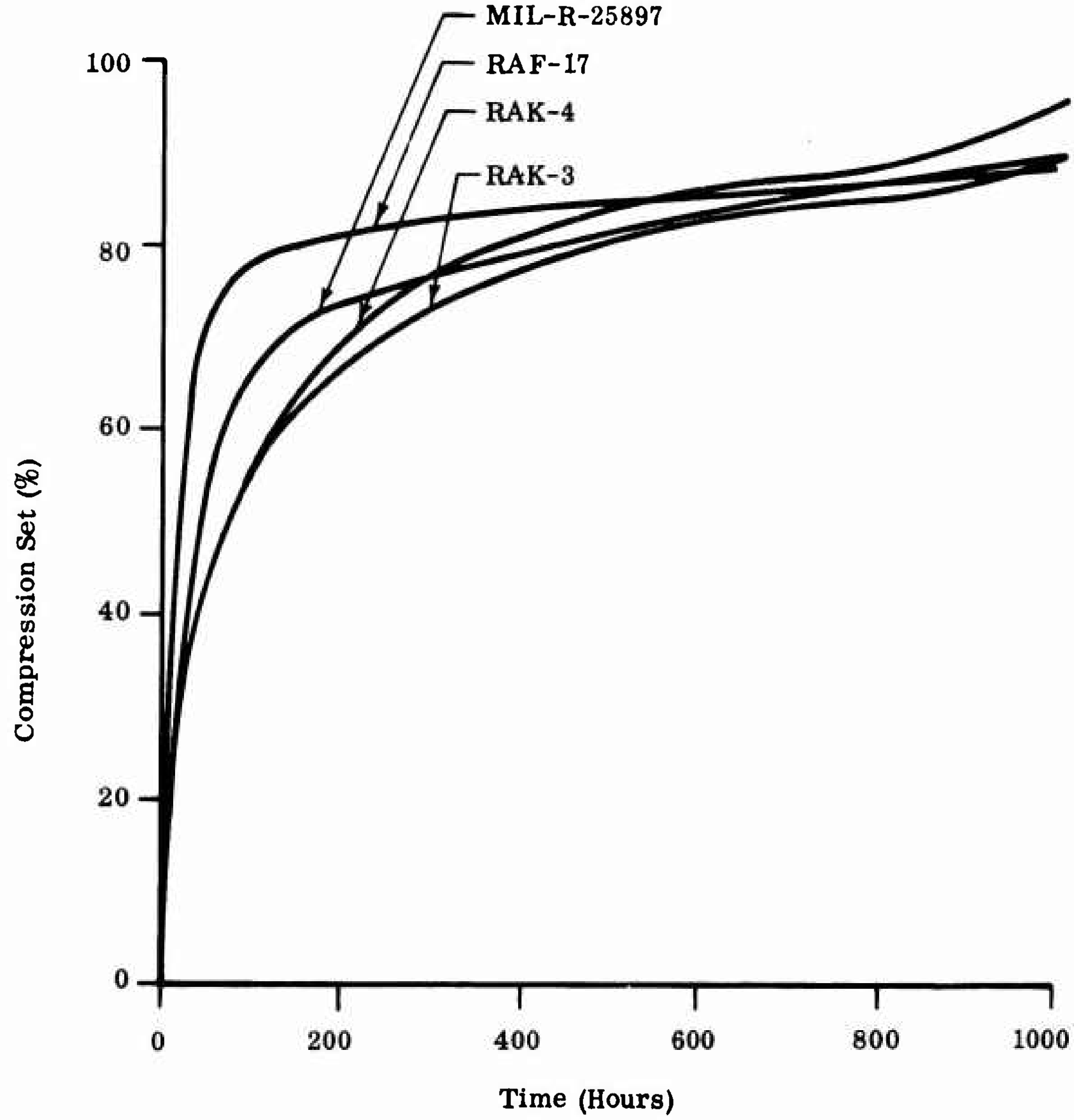


Figure 39. Long-Term Compression Set Characteristics for MIL-R-25897, RAF-17, RAK-3 and RAK-4 Compounds

in conjunction with the improved backup rings would be in the best interest of the program. The Dixon Corporation supplied Republic with a quantity of these rings. They were evaluated in dynamic cycling tests identical to those previously conducted. Unfortunately, a lack of time precluded extensive testing of these rings.

After 20,000 cycles these Dixon rings showed only minor extrusion. The 19 degree scarf angle permits the backup ring to mate more smoothly. Apparently this material has a lower coefficient of thermal expansion, for the characteristic overlap of MS28774 backup rings at the scarf cut and resulting indentation in the O-ring were completely absent. Although the evaluation of these reinforced Teflon backup rings was not as extensive as might be desired, it was strongly indicated that they will probably provide superior service as backup rings.

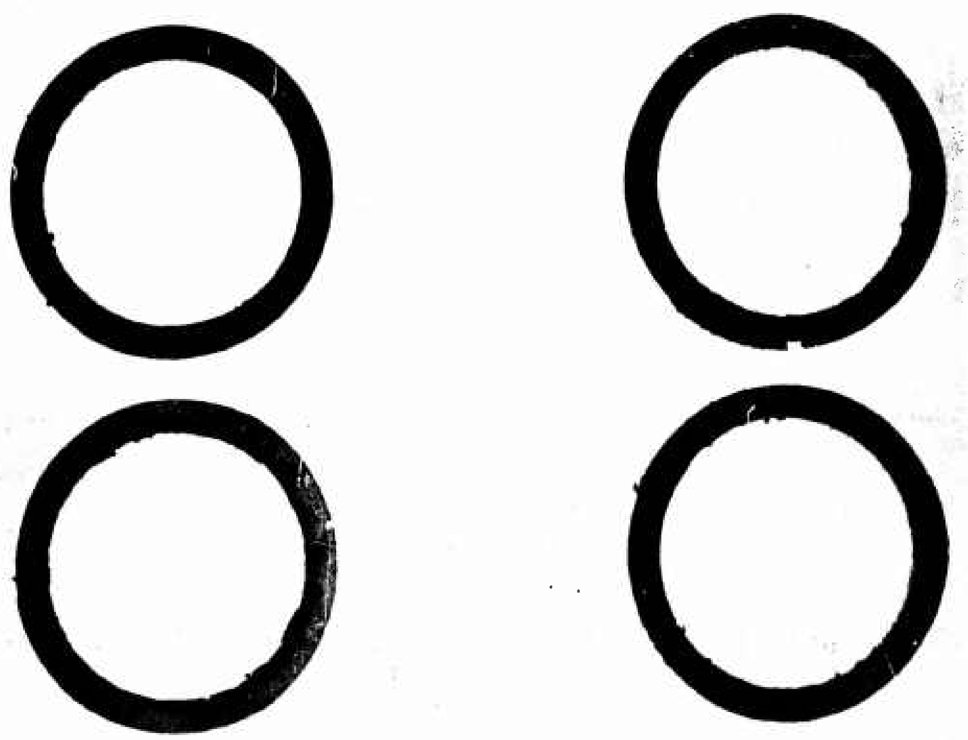


Figure 40. Typical MS28774 Backup Rings After 5000 Cycles at 275°F

SECTION IV
CONCLUSIONS

For 3000 psi service in hydraulic systems using MIL-H-5606 fluids at 275°F, MIL-P-25732 O-rings that receive some exposure to air indicate a life between 200 and 300 hours. Compression set is almost 100% under these conditions, and the rings become brittle. When used in applications where they receive little or no exposure to air, their service life appears to be closer to 500 hours, and compression set is substantially reduced.

MIL-R-25897 compounds used under identical conditions display inadequate extrusion resistance and poor low temperature performance. Compression set accumulates rapidly and seal life may be as low as 100 hours when one side of the O-ring is exposed to air.

Two experimental compounds were developed and tested that appear superior to either of the aforementioned compounds. These experimental compounds evidently present better balances of desirable qualities, as demonstrated by their greater functional life.

Compound RAF-54 utilized ECD-487, a low temperature Viton polymer produced by E. I. Du Pont de Nemours & Co. Although no appreciable improvement in compression set was realized, its better low temperature flexibility provided adequate low temperature sealing. The compound had been formulated to be more extrusion resistant than the MIL-R-25897 compounds, and thus provided improved performance. Exposure to air seemed to have little effect on the performance of the seals. They appear capable of 500 hours of life under these conditions in comparison to 400 hours when aged completely in oil.

Compounds were produced using Hydrin 200, an epichlorohydrin copolymer, produced by the B. F. Goodrich Company. The original -65°F sealing capability of the epichlorohydrin O-rings is not superior to the MIL-P-25732 buna N compounds, but it is expected to be superior after aging at 275°F has been experienced. Compound RAK-3 displayed 600 hours life with air exposure and 700 hours with oil. Compression set with air exposure accrued relatively slowly, approaching 90%. It did exhibit a tendency to soften after long periods at 275°F in MIL-H-5606 oil.

Hydrin 200 is a new polymer on which only a limited number of formulations were conducted. Thus it is highly probable that further property improvement can be achieved through additional compounding and through cure schedule studies as well. Compound RAK-26 indicated that secondary cures at 300°F can be of value in reducing compression set. Although not subjected to functional tests, the physical property data indicated that compound RAK-26 should perform well. Its low elongation did not permit establishing a TR-10 value; however, it probably possessed good low temperature flexibility. Hydrin 200 appears to be the most promising material since it is easily processed, moderate in cost, and should be available in production quantities in the future.

In summary, performance evaluations of the epichlorohydrin O-rings indicated that an increase in service life of 50 to 100% can be expected over buna N compounds under static and dynamic conditions when completely immersed in hydraulic fluid. In addition, 100 to 200% increase in service life can be expected when the seals are partially exposed to air. There is no increase in life for the ECD-487 over buna N when completely immersed in hydraulic fluid, but there is an increase of 150 to 300% when partially exposed to air.

A plasticizer with low volatility is not currently available, but would provide a valuable tool with which the compounder could produce more versatile rubber compounds.

The failure mechanism of dynamic seals is worthy of review, since it points the direction for improving the seal life. The failure sequence, described below, has been quite apparent during the course of the current program. When the O-ring is new and has good physical properties, it aids in centering the piston rod in the gland bore, thus acting as a bearing. The diametral clearance between the piston rod and the gland shoulder can be as large as 0.006 inch for a standard one-inch rod seal configuration. As time-at-temperature accrues, compression set of the O-ring progressively decreases its ability to center the piston rod. Side loads on the rod increase the stress level on one side of the O-ring, inducing further compression set. As a result, the chrome plated steel piston rod eventually rests solidly on the metal gland shoulder and, under dynamic stroking, wear particles are generated. In the test program these wear particles were observed being driven across the sealing surface and abrading the O-ring.

This condition is further aggravated when the backup ring extrudes into the diametral clearance gap. If extrusion were to occur symmetrically around the circumference of the gland bore, the result might be beneficial, since it would now tend to act as a good low-friction bearing surface. However, extrusion is usually asymmetrical, thus wedging the piston rod hard against the gland shoulder. Subsequent dynamic cycling generates additional wear particles because of the increased side force resulting from this wedging action. It has been found that the greatest amount of O-ring abrasion is caused by the presence of wear particles, rather than by direct rubbing of the rod on the O-ring. Thus, if gland wear can be minimized, major reductions in abrasion should result.

MS28774 backup rings that were used in conjunction with the dynamic tests proved marginal. They rapidly extruded into the clearance gap and, in some cases, total failure occurred. This deficiency was circumvented during testing by replacing them periodically (every 5000 cycles). However, it seems probable that, in actual field service, backup ring failure often precedes O-ring failure. The reinforced Teflon backup rings that were evaluated at the conclusion of the program appear distincly superior to the existing backup rings.

SECTION V

RECOMMENDATIONS

Additional formulations with the Hydrin 200 copolymer appear to be in order. The limited number of trials (30) with this material have undoubtedly not fully exploited its potential. Particular emphasis should be placed on techniques to improve compression set resistance and heat resistance. Secondary oven cures have shown promise in improving the latter property. The use of Hydrin 200 O-rings in conjunction with reinforced Teflon backup rings in actual applications should also be investigated.

Compression set effects can be partially circumvented with improved piston rod bearings that take out side loads and rod deflection. This would minimize the generation of abrasive gland wear particles, thus reducing O-ring abrasion and permitting the ring to seal effectively even though some compression set had taken place. Investigations should be conducted to determine the most suitable materials, clearances, and installation techniques for these piston rod bearings. Carbon graphites, polyimide resins (loaded and unloaded) and loaded teflons all appear to be candidate materials. Judicious matching of bearing material to the gland and the piston rod would provide minimum differential expansion changes in running clearances over the temperature range (-65° to +275°F). The findings of this investigation should then be incorporated in MIL-C-5503, the governing Military Specification for aircraft hydraulic cylinders.

The range of finishes of the piston rod should also be more precisely specified. MIL-P-5514 currently permits a 16 rms (maximum) surface finish for both the cylinder bore and the piston rod. Normal practice is to specify a value between 8 and 16 rms, a significant variation. The effects of surface finish pattern should also be investigated. The pattern of surface finish resulting from grinding is necessarily short pitched in comparison to that produced by honing or lapping. It is believed that such grind patterns, even though of equivalent measured surface finish to a honed or lapped rod, may be significantly more detrimental to packing and bearing life. Important results of these investigations could be reflected in MIL-P-5514.

Loaded Teflon backup rings with better extrusion resistance than existing MS28774 rings have already been developed under BuWeps Contract N156041574. These should be combined with the sealing advances resulting from AF33(615)-1668.

Contract AF33(615)-1668 has also indicated the need for a non-volatile plasticizer that would impart good low temperature flexibility to elastomers. Such a material could extend the service life of butadiene-acrylonitrile and epichlorohydrin compounds and allow fluoroelastomers and polyacrylates to have improved flexibility even after the normal high temperature secondary oven cures.

Such a program might commence with a volatility and solubility study of existing plasticizers and then be extended to related derivatives of the most promising candidates. Organic chemicals not normally classified as plasticizers, but which may be applicable, should also be included in such a study.

APPENDIX I

Proposed

MILITARY SPECIFICATION

PACKING, PREFORMED, PETROLEUM HYDRAULIC FLUID
RESISTANT, 275°F

1. PURPOSE

1.1 This document cutlines proposed test methods for the qualification of O-ring packings intended for use in aircraft hydraulic systems utilizing MIL-H-5606 fluid at rated service pressures up to 3000 psi and temperatures ranging from -65°F to +275°F. It will also serve as the basis for the future preparation of a complete packing specification after basic elastomer types have been established by capability of performance.

2. REFERENCE DOCUMENTS

MIL-P-5514
MIL-P-25732
MIL-H-5606
ASTM D1414, ASTM D676, ASTM D471
MS28775 (Note: This standard is referred to for the purpose of defining O-ring sizes and tolerances only.)

3. REQUIREMENTS

3.1 The items utilized in the tests covered in this specification shall be fabricated from materials appropriate for use in MIL-H-5606 hydraulic fluid. These materials shall contain no substance which, when in contact with the fluid, will adversely affect the properties of the fluid or the packings.

3.2 The packing material shall be homogenous to ensure uniformity of characteristics as determined by the physical properties.

4. DESIGN AND CONSTRUCTION

5. QUALIFICATION TESTS

5.1 Sampling Instructions - Qualification test samples shall consist of O-ring packing sizes per MS28775-214 size plus 6 ASTM Hardness Test Discs 1/4" thick by 1" dia. The quantity of packings to be used is shown in Table 1.

Table I

Test Samples Required for Qualification Testing

Aging Condition	Physical Properties Test for:	No. of samples of MS28775-214 O-rings
Unaged	Specific gravity.	2
	Tensile strength, ultimate elongation, and tensile stress (modulus). Hardness*	3
	Temperature retraction, 50 percent elongation and 10 percent return.	2
Air-aged 96 hrs @ 275°F	Tensile strength and elongation Hardness*	3
Oil-aged 168 hrs @ 275°F MIL-H-5606 oil	Tensile strength, elongation, and tensile stress (modulus) Hardness*	3
	Volume change** (MIL-H-5606 oil)	4
Air-aged 70 hrs @ 275°F	Permanent set (compressive)	2

* Hardness tests to be performed on test plugs as specified in paragraph 6.3 (6 plugs required)

** Use rings from specific gravity test

Note: The original and final physical properties as well as the performance tests are of prime importance. Additional testing related to corrosion and adhesion as specified in MIL-P-25732 will be developed as necessary. The sizes and numbers of O-ring test samples may be changed as details of test fixtures are finally developed.

Table II

Original Physical Properties

Hardness at 75° ± 5°F (Shore A durometer points)	70 min.
Tensile strength (psi)	1800 psi min.
Tensile stress (modulus) At 100% elongation (psi)	1100 psi min.
Ultimate elongation (percent)	150 min.
Temperature retraction, 50 percent elongation and 10 percent return	-45°F max.
Volumetric change after aging in hydraulic oil (percent)	0 to + 15
Permanent set (compressive) (percent)	50 max.
Other properties	As determined

6. TEST METHODS

6.1 The qualification tests of hydraulic packing shall consist of tests to determine the following properties.

- Specific gravity
- Tensile strength
- Ultimate elongation
- Tensile stress (modulus)
- Permanent set in compression
- Temperature retraction
- Hardness
- Volume swell

6.2 The physical properties listed in Table I shall be determined from aged and unaged samples by the methods described in the following paragraphs. The aging conditions are described in Table I. The manufacturers shall report all values. This shall be done during qualification tests only.

6.3 Hardness of the compound shall be determined in accordance with ASTM Method D676.

6.3.1 These hardness checks shall be made with the sample at room temperature, + 70°F (± 5°F).

6.4 Tensile strength, ultimate elongation, tensile stress (modulus) and permanent set for the material shall be conducted on actual qualification samples submitted for test. The quantities and sizes of the samples to be tested shall be as specified in Table I and Paragraph 5.1.

6.4.1 Tensile strength shall be determined in accordance with ASTM Method D1414.

6.4.2 Ultimate elongation shall be determined in accordance with ASTM Method D1414.

6.4.3 Tensile stress (modulus) at 100% elongation shall be determined in accordance with ASTM Method D1414.

6.5 Permanent set (compressive) shall be determined in the manner described in ASTM Method D1414.

6.6 Volume change shall be determined as specified in ASTM Method D471 after aging for 168 hours in MIL-H-5606.

6.7 Specific gravity shall be determined from the finished O-ring samples in accordance with ASTM Method D1414.

6.8 Temperature retraction tests on samples are to be conducted in accordance with ASTM Method D1414.

7. PERFORMANCE TESTING

The performance tests shall consist of the test sequences as outlined in the following paragraphs. All of these tests shall be performed with the sample packings assembled in test fixtures similar in design and construction to those shown in Figures 1, 2, and 3. The temperatures of the packing test fixtures shall be determined by the suitable placement of thermocouples.

7.1 Static Seal Tests

7.1.1 Oil-Aging Tests

7.1.1.1 Install MS 28775-214 size packings in a test cylinder similar to that shown in Figure 1.

7.1.1.2 Soak the packing in MIL-H-5606 oil at 275 ±5°F for 100 hours while installed in the test cylinder. Ensure that the rings are completely surrounded by oil and that no air pockets exist. At the conclusion of 100 hours remove the test cylinder from the oil bath.

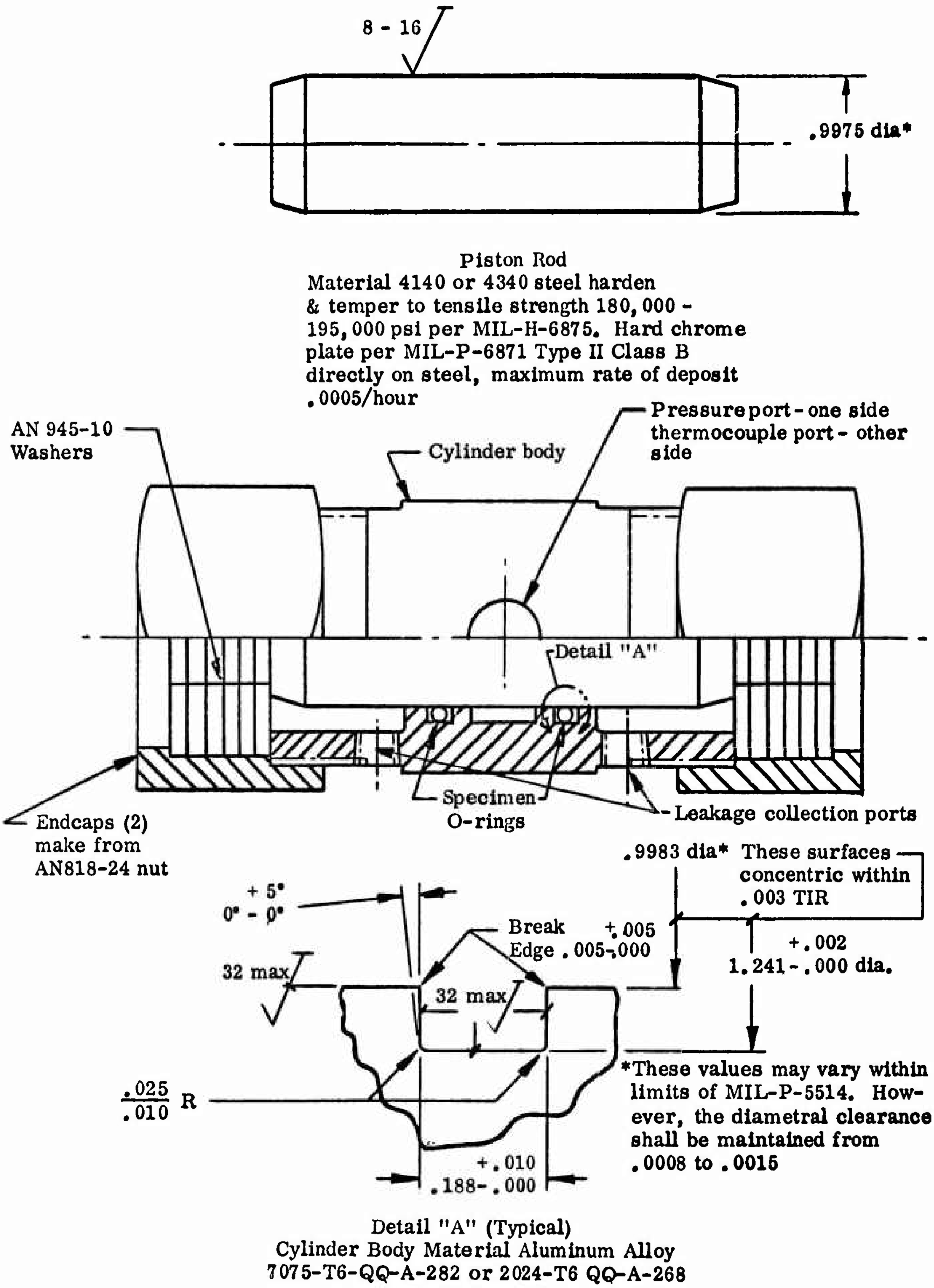


Figure 1. Static Test Cylinder

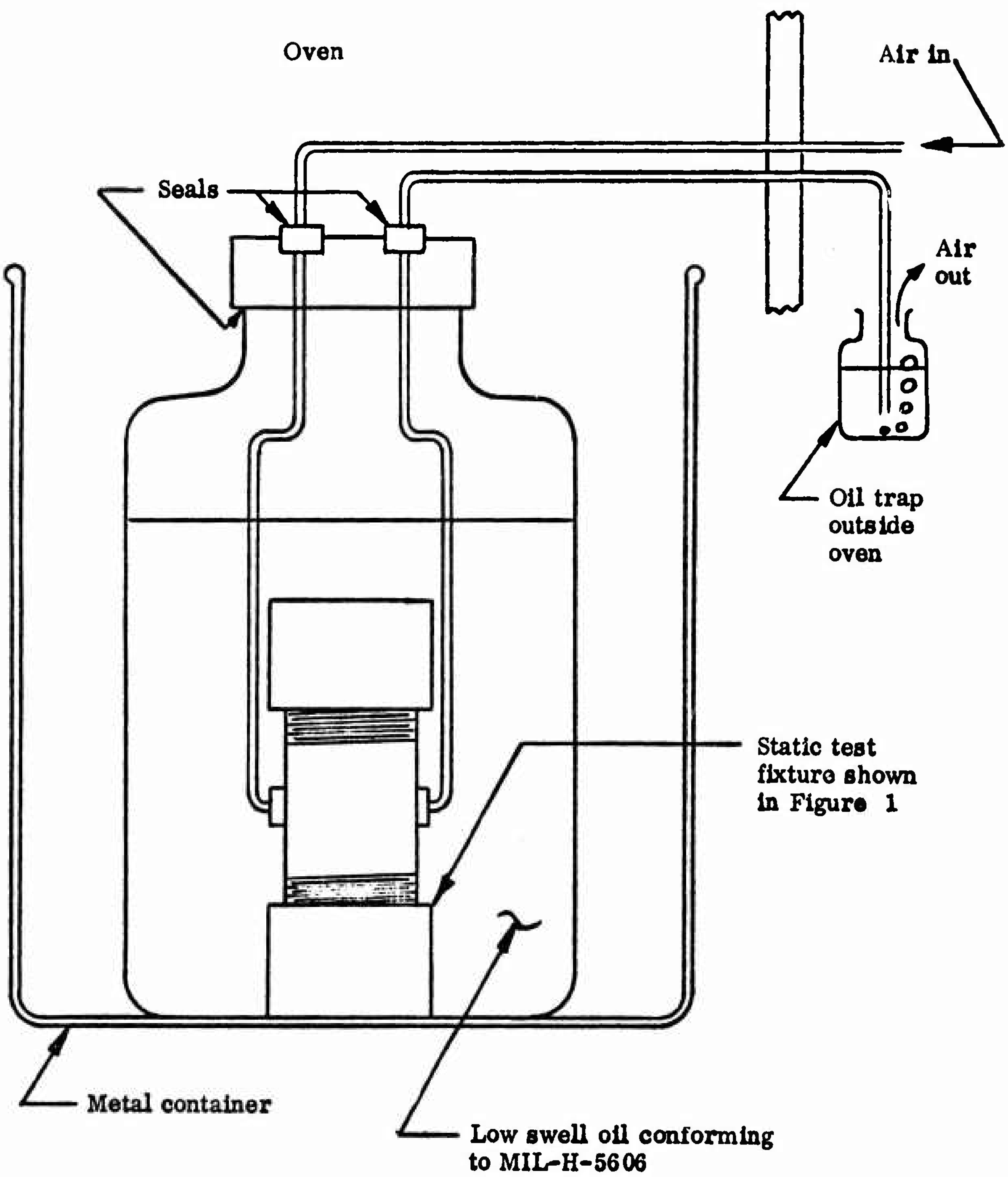


Figure 2. Air Aging System

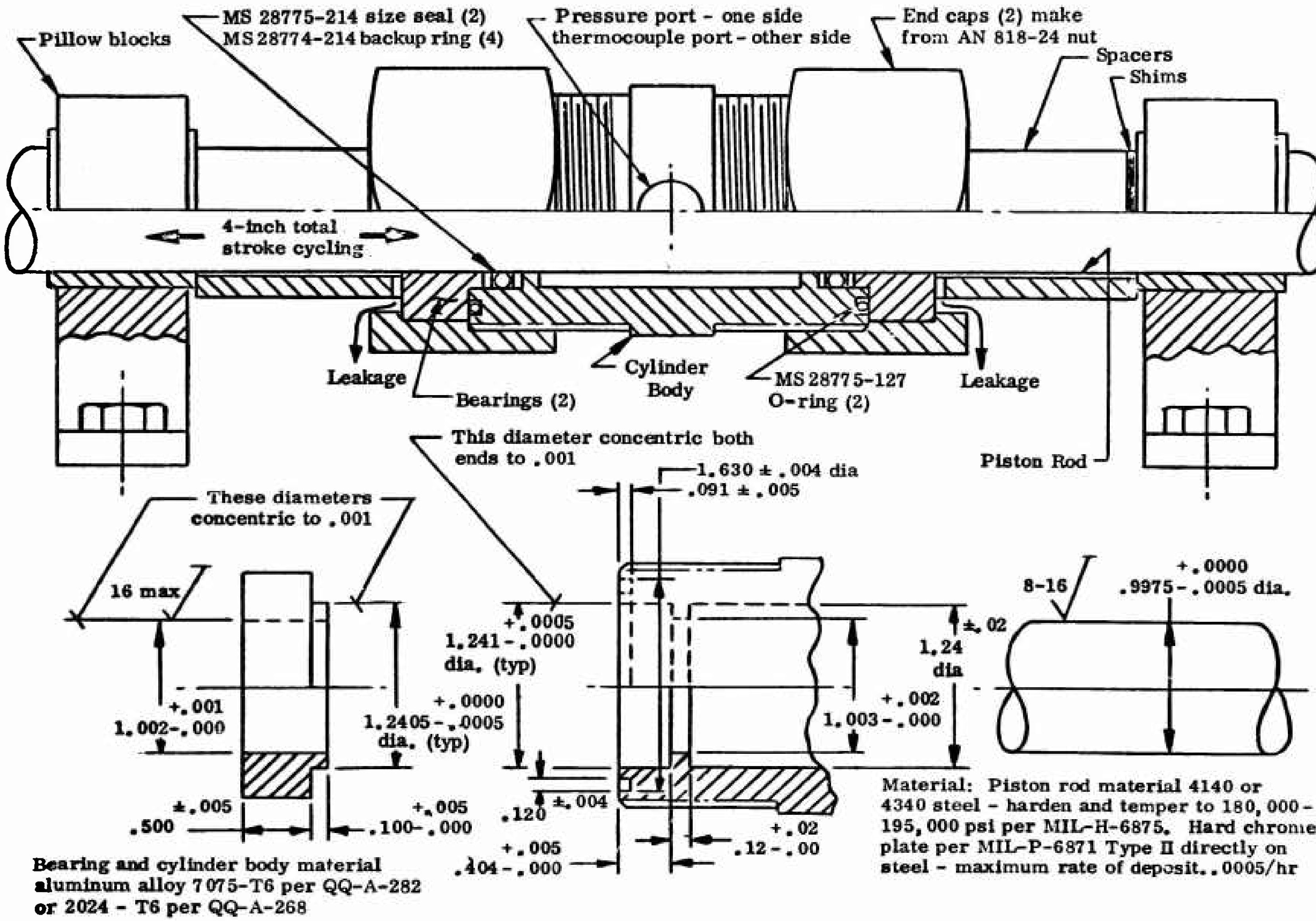


Figure 3. Dynamic Test Cylinder

7.1.1.3 Install the test cylinder in a static test system capable of attaining the environmental requirements of -65°F and +275°F. This system should also provide a source of MIL-H-5606 fluid and a valving system which can vary the applied pressure from 0 - 75 psi to 3000 ± 50 psi at a rate of 30 cycles per minute. The rate of rise of pressure shall be 25,000 psi/second minimum. The test cylinder should be completely full of oil. The source of MIL-H-5606 fluid should be connected to the pressure port of the test cylinder. Suitable means for collecting and measuring leakage from the packings during testing shall be provided.

7.1.1.4 Lower the temperature of the test cylinder to -30°F and stabilize, then leak check with 50 psi steady pressure for one hour.

7.1.1.5 Reduce temperature to -65° and stabilize, then leak check with a 2-foot head of pressure for one hour.

7.1.1.6 Initiate pressure cycling from 0 - 75 psi to 3000 psi at 30 ± 5 cycles per minute and initiate environmental heating. Accomplish temperature rise to +275°F within 40 minutes and stabilize. Complete a total of 10,000 pressure cycles.

7.1.1.7 Leakage shall be recorded throughout the entire test. Leakage in excess of 100 drops from both ends of the test cylinder during steps 7.1.1.4, 7.1.1.5, and 7.1.1.6 shall be considered a failure.

7.1.1.8 Steps 7.1.1.2, 7.1.1.3, 7.1.1.4, 7.1.1.5, 7.1.1.6 and 7.1.1.7 shall all be repeated 5 additional times.

7.1.2 Air-Aging Tests

7.1.2.1 Install MS28775-214 size packings in a test cylinder similar to that shown in Figure 1. Connect the air inlet line to the pressure port. Connect the air outlet line to the thermocouple port. Submerge the test fixture MIL-H-5606 oil and age for 100 hours at 275°F. Ensure that air is circulating through the internal cavity during the aging period by putting the air outlet line into an oil trap where a bubble rate of 60 bubbles per minute is visible. The system is shown in Figure 2.

7.1.2.2 At the conclusion of 100 hours of aging, reverse the O-rings in the cavity so that the side exposed to air during aging will now be exposed to air during pressure cycling.

7.1.2.3 Install the test cylinder in the static test system described in 7.1.1.3.

7.1.2.4 Lower the temperature of the test cylinder to -30°F and stabilize; then leak check with 50 psi steady pressure for one hour.

7.1.2.5 Reduce the temperature to -65° and stabilize; then leak check with a 2-foot head of pressure for one hour.

7.1.2.6 Initiate pressure cycling from 0 - 75 psi to 3000 psi at 30 ± 5 cycles per minute and initiate environmental heating. Accomplish temperature rise to +275°F within 40 minutes and stabilize. Complete a total of 10,000 pressure cycles.

7.1.2.7 Leakage shall be recorded throughout the entire test. Leakage in excess of 100 drops from both ends of the test cylinder during steps 7.1.2.4, 7.1.2.5 and 7.1.2.6 shall be considered a failure.

7.1.2.8 Reverse the O-rings in the static test cylinder so that the side exposed to air during aging will again be exposed to air during the next aging period.

7.1.2.9 Steps 7.1.2.1, 7.1.2.2, 7.1.2.3, 7.1.2.4, 7.1.2.5, 7.1.2.6, 7.1.2.7 and 7.1.2.8 shall all be repeated 5 additional times.

7.2 Dynamic Seal Tests

7.2.1 Oil-Aging Tests

7.2.1.1 Install MS28775-214 size packings in a test cylinder similar to that shown in Figure 1.

7.2.1.2 Soak packings in MIL-H-5606 oil at + 275 ± 5°F for 100 hours while installed in the test cylinder without backup rings. Ensure that the rings are completely surrounded by oil and that no air pockets exist. At the conclusion of 100 hours remove the test cylinder from the oil bath.

7.2.1.3 Install the test cylinder in a static test system similar to that described in paragraph 7.1.1.3.

7.2.1.4 Reduce the temperature of the test cylinder to -30°F and stabilize; then leak check with 50 psi steady pressure for one hour.

7.2.1.5 Reduce the temperature to -65°F and stabilize; then leak check with a 2-foot head of pressure for one hour.

7.2.1.6 Allow the test cylinder to return to room temperature.

7.2.1.7 Remove the specimen O-rings from the static test cylinder and install them in a dynamic test cylinder, similar to that shown in Figure 3, with unused MS28774-214 backup rings on each side of the O-rings.

7.2.1.8 Install the test cylinder in a dynamic test system. The dynamic test system shall be capable of attaining the environmental requirements of -65°F and + 275°F. This system shall have a source of MIL-H-5606 fluid and the ability to maintain this fluid at pressures up to 3000 psi. The test system shall also have the ability to stroke the piston rod for a total stroke of 4 inches. Suitable means for collecting and measuring leakage from the packings during testing shall be provided.

7.2.1.9 Reduce the temperature of the test cylinder to -65°F and stabilize.

7.2.1.10 Apply 3000 psi continuous pressure and initiate 4-inch total stroke cycling at 30 cycles per minute. Initiate environmental heating and effect temperature rise to +275°F within one hour after cycling is started. Maintain +275°F temperature. Complete 10,000 dynamic stroke cycles.

7.2.1.11 Leakage shall be recorded throughout the entire test. Leakage in excess of 100 drops from both ends of the test cylinder during steps 7.2.1.4, 7.2.1.5, and 7.2.1.10 shall be considered a failure.

7.2.1.12 Steps 7.2.1.1, 7.2.1.2, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.2.1.6, 7.2.1.7, 7.2.1.8, 7.2.1.9, 7.2.1.10, and 7.2.1.11 shall all be repeated 4 additional times.

7.2.2 Air-Aging Tests

7.2.2.1 Install MS28775-214 size packings in a test cylinder similar to that shown in Figure 1. Connect the air inlet line to the pressure port. Connect the air outlet line to the thermocouple port. Submerge the test fixture in MIL-H-5606 fluid and age for 100 hours at 275°F. Ensure that air is circulated throughout the internal cavity during the aging period by putting the air outlet line into an oil trap where a bubble rate of 60 bubbles per minute is visible. The system is shown in Figure 2.

7.2.2.2 At the conclusion of 100 hours of aging, reverse the O-rings so that the side exposed to aging will now be exposed to air during the low temperature leakage checks.

7.2.2.3 Install the test cylinder in a static test system similar to that described in 7.1.1.3.

7.2.2.4 Reduce the temperature of the test cylinder to -30°F and stabilize; then leak check with 50 psi steady pressure for one hour.

7.2.2.5 Reduce the temperature to -65°F and stabilize; then leak check with a 2-foot head of pressure for one hour.

7.2.2.6 Allow the test cylinder to return to room temperature.

7.2.2.7 Remove the specimen O-rings from the static test cylinder and install them in a dynamic test cylinder, similar to that shown in Figure 3, with unused MS 28774-214 backup rings on each side of the O-rings. Ensure that the side of the O-ring which was exposed to air during aging and low temperature tests remains exposed to air during dynamic cycling.

7.2.2.8 Install the dynamic test cylinder in a dynamic test system similar to that described in 7.2.1.8.

7.2.2.9 Reduce the temperature of the test cylinder to -65°F and stabilize.

7.2.2.10 Apply 3000 psi continuous pressure and initiate 4-inch total stroke cycling at 30 cycles per minute. Initiate environmental heating and effect a temperature rise to +275°F within one hour after cycling is started. Maintain +275°F temperature. Complete 10,000 dynamic stroke cycles.

7.2.2.11 Leakage shall be recorded throughout the entire test. Leakage in excess of 100 drops from both ends of the test cylinder during steps 7.2.2.4, 7.2.2.5, and 7.2.2.10 shall be considered a failure.

7.2.2.12 Steps 7.2.2.1, 7.2.2.2, 7.2.2.3, 7.2.2.4, 7.2.2.5, 7.2.2.6, 7.2.2.7, 7.2.2.8, 7.2.2.9, 7.2.2.10, and 7.2.2.11 shall all be repeated 4 additional times.

7.2.3 Unused MS28774 backup rings shall be installed prior to each 10,000 dynamic stroke cycles conducted in the dynamic cycling tests.

7.3 During both static and dynamic air-aging tests, the side of the O-ring exposed to air during the initial aging cycle shall remain exposed to air during all cycling tests and subsequent aging cycles.

APPENDIX II - DESCRIPTION OF EXPERIMENTAL COMPOUNDS

A qualitative and quantitative description of experimental compounds developed during the reporting period, including their cure schedules and physical properties, is given in Tables I through LXXXVI on the following pages.

TABLE I - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-11	RAF-12	RAF-13	RAF-16	RAF-17	RAF-20	RAF-21
Viton B	100.0	100.0	--	--	--	100.0	100.0
ECD 487 HV (lot B)	--	--	100.0	100.0	100.0	--	--
G. E. SE-450 (semi-cured)	--	--	--	--	--	--	50.0
Calcium oxide	15.0	15.0	--	--	--	--	--
Maglite Y	--	--	15.0	15.0	15.0	15.0	15.0
MT Black	20.0	--	--	--	20.0	60.0	80.0
Carbon Wool 3B1	--	15.0	40.0	30.0	--	--	--
TP-95	--	--	--	--	--	20.0	--
Diak No. 3	3.0	3.0	--	--	--	3.0	3.0
Diak No. 1	--	--	3.0	3.0	3.0	--	--
	138.0	133.0	158.0	148.0	138.0	198.0	248.0
Press cure	8 min/ 332°F	8 min/ 332°F	30 min/ 300°F	30 min/ 300°F	30 min/ 300°F	30 min/ 400°F	8 min/ 330°F
Secondary oven cure	1 hr/ 212°F 1 hr/ 250°F 1 hr/ 300°F 1 hr 350°F 1 hr/ 400°F 20 hrs/ 480°F	1 hr/ 212°F 1 hr/ 250°F 1 hr/ 300°F 1 hr 350°F 1 hr/ 400°F 20 hrs/ 480°F	24 hrs/ 400°F 24 hrs/ 450°F 24 hrs/ 500°F	24 hrs/ 400°F 24 hrs/ 450°F 24 hrs/ 500°F	24 hrs/ 400°F 24 hrs/ 450°F 24 hrs/ 500°F	--	24 hrs/ 400°F

TABLE II - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-11	RAF-12	RAF-13	RAF-16	RAF-17	RAF-20	RAF-21
Original Properties							
Shore A hardness	77	83	92	89	82	69	77
Tensile strength, psi	1841	1584	2314	1862	2162	410	549
Elongation	310%	170%	70%	50%	270%	220%	175%
Tensile stress, 100%, psi	684	1283	--	--	837	231	349
Temperature retraction				+17°F	-18°F	-43°F	-8°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	75 (-2)	81 (-2)	90 (-2)	88 (-1)	82 (0)	84 (+15)	67 (-10)
Tensile strength, psi	1197	1330 (-16%)	1820 (-21%)	1872 (0)	2093 (-3%)	667 (+63%)	424 (-22%)
Elongation	270%(-13%)	150%(-12%)	75%(+7%)	50%(0)	260%(-3%)	160%(-27%)	145%(-17%)
Tensile strength, 100%, psi	535 (-22%)	1144 (-10%)	--	--	826 (0)	487 (+111%)	299 (-14%)
Volume change	+6.4%	+5.2%	+1.9%	+3.3%	+2.9%	-3.4%	+13.7%
Air-Aged 96 hrs/275°F							
Shore A hardness	80 (+3)	85 (+2)	91 (-1)	90 (+1)	84 (+2)	84 (+15)	79 (+2)
Tensile strength, psi	1635 (-11%)	1463 (-7%)	1934 (-16%)	1704 (-8%)	2397 (+11%)	590 (+44%)	449 (-18%)
Elongation	290%(-6%)	160%(-6%)	70%(0)	50%(0)	250%(-7%)	110%(-50%)	143%(-18%)
Tensile stress 100%, psi	649 (-5%)	1224 (-5%)	--	--	976 (-17%)	539 (+133%)	371 (+6%)
Compression Set							
70 hrs/275°F	19%	17%	14%	13%	24%	76%	56%

TABLE III - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-22	RAF-23	RAF-24	RAF-25	RAF-26	RAF-28	RAF-29
ECD487HV (lot B)	--	--	--	--	--	--	100.0
Viton A-HV	--	50.0	--	--	--	--	--
Dynagen XP139	--	50.0	--	--	--	--	--
Viton B	100.0	--	100.0	95.0	95.0	--	--
Butyl HT1066	--	--	--	5.0	5.0	--	--
Fluorel 2140	--	--	--	--	--	100.0	--
Silastic 651 (semi-cured)	50.0	--	--	--	--	--	--
Carbon Wool 3 Bl	--	--	--	--	--	--	20.0
MT Black	80.0	--	75.0	75.0	75.0	50.0	25.0
Maglite	15.0	8.0	15.0	--	--	--	15.0
Blanc Fixe	--	50.0	--	--	--	--	--
Cab-O-Sil MS-7	--	15.0	--	--	--	--	--
Di Cup 40C	--	6.0	--	--	--	--	--
Calcium oxide	--	--	15.0	15.0	15.0	15.0	--
TP-95	--	--	17.5	17.5	17.5	20.0	--
Diak No. 3	3.0	--	--	--	--	--	--
Diak No. 1	50.0	--	2.0	2.0	3.0	2.0	3.0
	248.0	179.0	224.5	209.5	210.5	187.0	163.0
Press cure	8 min/ 330°F	30 min/ 330°F	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	30 min/ 300°F
Secondary oven cure	24 hrs/ 400°F	4 hrs/ 300°F	--	--	--	--	24 hrs/ 400°F 24 hrs/ 450°F 24 hrs/ 500°F

TABLE IV - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-22	RAF-23	RAF-24	RAF-25	RAF-26	RAF-28	RAF-29
Original Properties							
Shore A hardness	79	90	95	76	84	74	86
Tensile strength, psi	604	780	1426	435	415	705	1851
Elongation	120%	20%	97%	110%	50%	105%	63%
Tensile stress, 100%, psi	444	--	--	405	--	663	--
Temperature retraction	-7°F	--	*	*	--	-25°F	-20°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	65 (-14)	82 (-8)	93 (-2)	79 (+3)	89 (+5)	85 (+11)	86 (0)
Tensile strength, psi	516 (-14%)	383 (-51%)	1488 (+4%)	574 (+32%)	524 (+26%)	1128 (+60%)	1517 (+18%)
Elongation	160%(+33%)	25%(+25%)	77%(-21%)	130 (+18%)	52%(+4%)	107%(0)	63%(0)
Tensile stress, 100%, psi	319 (-28%)	--	--	467 (+15%)	--	1053 (+59%)	--
Volume change	+19.9%	+23.1%	+6.2%	+1.9%	+4.3%	-5.2%	+2.6%
Air-Aged 96 hrs/275°F							
Shore A hardness	80 (+1)	84 (-6)	97 (+2)	88 (+12)	89 (+5)	85 (+11)	85 (-1)
Tensile strength, psi	624 (+3%)	**	1680 (+18%)	699 (+61%)	636 (+53%)	1026 (+45%)	1663 (-10%)
Elongation	155%(+29%)	**	80%(-18%)	107%(-3%)	43%(-14%)	100%(-5%)	70%(+11%)
Tensile stress 100%, psi	428 (-4%)	**	--	683 (+69%)	--	1026 (+55%)	-
Compression Set							
70 hrs/275°F	52%	**	33%	55%	60%	57%	16%

** Test could not be made because properties of specimen were deficient.
* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE V - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS

	RAF-30	RAF-34	RAF-35	RAF-36	RAF-38	RAF-39	RAF-41
Fluorel K 2140	--	--	--	100.0	--	--	--
ECD487HV (lot B)	--	--	--	--	--	--	100.0
Viton B	100.0	100.0	--	--	100.0	100.0	--
Fluorel KX2150	--	--	100.0	--	--	--	--
Dyphos	--	--	--	50.0	--	--	--
MT Black	55.0	55.0	--	50.0	55.0	55.0	20.0
Calcium oxide	25.0	--	15.0	--	20.0	40.0	--
Maglite Y	--	--	--	--	20.0	--	15.0
Litharge	--	25.0	--	--	--	--	--
TP-95	20.0	20.0	20.0	20.0	17.5	17.5	--
Diak No. 1	2.0	2.0	--	2.0	2.0	2.0	--
Diak No. 3	--	--	3.0	--	--	--	--
Blanc Fixe	--	--	35.0	--	--	--	--
Tetramethyl guanidine	--	--	--	--	--	--	2.0
	202.0	202.0	173.0	222.0	214.5	214.5	137.0
Press cure	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--	--	--

TABLE VI - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS

	RAF-30	RAF-34	RAF-35	RAF-36	RAF-38	RAF-39	RAF-41
Original Properties							
Shore A hardness	75	66	56	82	78	74	45
Tensile strength, psi	321	227	451	885	320	239	490
Elongation	73%	100%	317%	125%	67%	75%	378%
Tensile stress 100%, psi	--	--	189	772	--	--	110
Temperature retraction	*	-24°F	-32°F	-21°F	*	*	*
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	80 (+5)	73 (+7)	71 (+15)	89 (+7)	83 (+5)	79 (+5)	**
Tensile strength, psi	393 (+22%)	339 (+49%)	649 (+44%)	1173 (+33%)	330 (+3%)	234 (-2%)	**
Elongation	53%(-27%)	73%(-27%)	160%(-50%)	100%(-25%)	47%(-30%)	37%(-51%)	**
Tensile stress 100%, psi	--	--	474 (151%)	1173 (+52%)	--	--	**
Volume change	+3.8%	+0.9%	-5.1%	-7.1%	-0.5%	-1.1%	**
Air-Aged 96 hrs/275°F							
Shore A hardness	82 (+7)	88 (+22)	70 (+14)	93 (+11)	93 (+15)	80 (+6)	**
Tensile strength, psi	347 (+8%)	401 (+77%)	880 (+95%)	1250 (+41%)	361 (+13%)	290 (+21%)	**
Elongation	53%(-27%)	43%(-57%)	185%(-41%)	85%(-32%)	37%(-45%)	42%(-44%)	**
Tensile stress 100%, psi	--	--	487 (+158%)	--	--	--	**
Compression Set							
70 hrs/275°F	43%	94%	57%	88%	46%	45%	**

* Test could not be completed - specimen failed at clamp when installed in apparatus.

** Test could not be made because properties of specimens were deficient.

TABLE VII - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-42	RAF-43	RAF-44	RAF-46	RAF-51	RAF-53	RAF-54
Fluorel K 2140	--	--	--	100.0	--	--	--
ECD487HV (Lot B)	--	--	--	--	--	--	100.0
Viton B	50.0	50.0	100.0	--	--	100.0	--
Cyanacril LT3	50.0	50.0	--	--	--	--	--
Fluorel 2140	--	--	--	--	100.0	--	--
MT Black	35.0	37.5	75.0	50.0	50.0	--	--
FEF Black	--	--	--	--	--	20.0	20.0
Maglite Y	--	--	20.0	20.0	--	--	15.0
Calcium oxide	15.0	15.0	--	--	--	15.0	--
Dyphos	--	--	--	--	50.0	--	--
TP-95	--	--	20.0	20.0	20.0	--	--
Tetramethyl guanidine	1.5	--	1.5	1.5	--	--	--
TETA	--	--	--	--	2.0	--	--
Diak No. 1	--	--	--	--	2.0	--	3.0
Diak No. 3	--	4.0	--	--	--	3.0	--
	151.5	156.5	216.5	191.5	224.0	138.0	138.0
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 400°F	8 min/ 330°F	30 min/ 300°F
Secondary oven cure	--	24 hrs/ 400°F	--	--	--	20 hrs/ 480°F	24 hrs/ 400°F 24 hrs/ 450°F 24 hrs/ 500°F

TABLE VIII - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-42	RAF-43	RAF-44	RAF-46	RAF-51	RAF-53	RAF-54
Original Properties							
Shore A hardness	44	95	56	51	80	90	86
Tensile strength, psi	511	1240	259	860	523	1987	2266
Elongation	195%	0%	193%	675%	30%	180%	187%
Tensile stress, 100%, psi	208	--	145	146	--	1110	1010
Temperature retraction	*	--	-12°F	-29°F	--	+8°F	-19°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	*	90 (-5)	84 (+28)	83 (+32)	95 (+15)	90 (0)	85 (-1)
Tensile strength, psi	*	*	*	1078 (+25%)	1449 (+171%)	1741 (-12%)	2244 (-1%)
Elongation	*	*	*	263%(-61%)	23%(-23%)	182%(+1%)	213%(+14%)
Tensile stress, 100%, psi	*	*	*	782 (+436%)	--	1028 (-7%)	901 (-11%)
Volume change	*	+17.2%	-6.7%	-5.0%	+25.6%	+4.6%	+3.3%
Air-Aged 96 hrs/275°F							
Shore A hardness	*	95 (0)	77 (+21)	65 (+14)	95 (+15)	92 (+2)	85 (-1)
Tensile strength, psi	*	1256 (+1%)	433 (+67%)	830 (-4%)	984 (+88%)	2077 (+5%)	2264 (0%)
Elongation	*	*	77%(-60%)	313%(-54%)	20%(-33%)	193%(+7%)	192%(+3%)
Tensile stress, 100%, psi	*	--	--	365 (+150%)	--	1137 (+2%)	926 (-8%)
Compression Set							
70 hrs/275°F	*	44%	100%	91%	*	26%	31%

* Tests could not be made because properties were deficient.

TABLE IX - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-55	RAF-57	RAF-59	RAF-60	RAF-64	RAF-65	RAF-67
Fluorel KX-2150	--	--	--	--	100.0	100.0	--
Cyanacril LT3	--	--	--	50.0	--	--	50.0
Viton A-HV	100.0	--	--	--	--	--	--
Viton B	--	100.0	--	50.0	--	--	50.0
Fluorel 2140	--	--	100.0	--	--	--	--
FEF Black	20.0	--	--	--	--	--	--
MT Black	--	50.0	50.0	40.0	--	--	35.0
Maglite Y	--	--	20.0	--	--	15.0	--
Maglite D	--	--	--	--	15.0	--	--
Calcium oxide	15.0	15.0	--	15.0	--	15.0	15.0
Diak No. 1	--	--	--	--	--	2.0	--
Diak No. 3	--	--	--	4.0	--	--	--
Diak No. 4	2.0	2.5	--	--	--	--	--
Tetramethyl quanidine	--	--	1.5	--	1.5	--	1.5
TP-95	--	15.0	20.0	--	--	17.5	--
	137.0	182.5	191.5	159.0	116.5	139.5	151.5
Press cure	8 min/ 330°F	45 min/ 330°F	30 min/ 330°F	30 min/ 330°F	45 min/ 330°F	60 min/ 400°F	30 min/ 330°F
Secondary oven cure	1 hr/ 350°F 1 hr/ 400°F 20 hrs/ 480°F	--	24 hrs/ 212°F	24 hrs/ 325°F	--	--	24 hrs/ 212°F

TABLE X - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-55	RAF-57	RAF-59	RAF-60	RAF-64	RAF-65	RAF-67
Original Properties							
Shore A hardness	81	69	67	87	78	64	54
Tensile strength, psi	1877	462	1305	1266	1424	604	561
Elongation	117%	148%	587%	60%	273%	120%	170%
Tensile stress, 100%, psi	1550	359	360	--	757	504	292
Temperature retraction	+5°F	-30°F	-30°F	*	+5°F	-31°F	-7°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	81 (0)	79 (+10)	80 (+13)	80 (-7)	78 (0)	71 (+7)	44 (-10)
Tensile strength, psi	1881 (%)	382 (-17%)	1269 (-3%)	815 (-36%)	1593 (+12%)	1029 (+70%)	304 (-46%)
Elongation	117%(0%)	83% (-44%)	267%(-55%)	50%(-17%)	210 (-23%)	112%(-7%)	102%(-40%)
Tensile stress, 100%, psi	1632 (+5%)	--	961 (+167%)	--	963 (+27%)	877 (+74%)	270 (-8%)
Volume change	+5.1%	-0.9%	-15.1%	+18.4%	+1.0%	-1.0%	+28.7%
Air-Aged 96 hrs/275°F							
Shore A hardness	83 (+2)	78 (+9)	80 (+13)	89 (+2)	80 (+2)	75 (+11)	56 (+2)
Tensile strength, psi	1947 (+4%)	623 (+35%)	1095 (-16%)	1260 (-5%)	1844 (+29%)	931 (+54%)	503 (-10%)
Elongation	107%(-9%)	123%(-18%)	257%(-57%)	50%(-17%)	225%(-18%)	140%(+17%)	123%(-28%)
Tensile stress, 100%, psi	1635 (+6%)	519 (+45%)	538 (+50%)	--	1079 (+43%)	735 (+46%)	382 (+31%)
Compression Set							
70 hrs/275°F	9%	67%	85%	53%	75%	35%	59%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XI - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-68	RAF-69	RAF-70	RAF-71	RAF-72	RAF-73
Fluorel KX-2150	--	--	--	75.0	--	--
Viton A	--	--	--	--	100.0	--
Cyanacril LT3	15.0	15.0	25.0	25.0	--	--
Fluorel 2140	85.0	85.0	--	--	--	--
Viton A-HV	--	--	75.0	--	--	100.0
MT Black	42.5	42.5	--	--	--	--
FEF Black	--	12.5	45.0	25.0	40.0	40.0
Calcium oxide	--	--	15.0	--	--	--
Maglite Y	20.0	20.0	--	--	--	--
Maglite D	--	--	--	15.0	15.0	20.0
TP-95	10.0	10.0	--	10.0	--	--
Tetramethyl quanidine	1.5	1.5	--	1.5	2.0	1.5
Diak No. 4	--	--	2.0	--	--	--
	174.0	186.5	162.0	151.5	157.0	161.5
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	24 hrs/ 212°F	24 hrs/ 212°F	24 hrs/ 275°F	24 hrs/ 250°F	24 hrs/ 212°F	--

TABLE XII - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-68	RAF-69	RAF-70	RAF-71	RAF-72	RAF-73
Original Properties						
Shore A hardness	58	71	92	64	85	80
Tensile strength, psi	853	1000	1786	1105	1538	1658
Elongation	363%	220%	70%	187%	170%	247%
Tensile stress, 100%, psi	373	618	--	611	877	632
Temperature retraction	-18°F	-15°F	*	-17°F	-3°F	-10°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	65(+7)	76(+5)	88(-4)	61(-3)	95(+10)	93(+13)
Tensile strength, psi	1000(+17%)	1180(+18%)	1619(-9%)	916(-17%)	1618(+5%)	2182(+32%)
Elongation	217%(-41%)	130%(-41%)	75%(+7%)	127%(-32%)	77%(-55%)	100%(-59%)
Tensile stress, 100%, psi	566(+52%)	967(+57%)	--	697(+14%)	--	2111(+234%)
Volume change	-0.2%	-0.3%	+16.4%	+3.9%	-5.7%	-7.5%
Air-Aged 96 hrs/275°F						
Shore A hardness	63(+5)	75(+4)	93(+1)	69(+5)	96(+11)	88(+8)
Tensile strength, psi	1098(+29%)	1285(+29%)	2168(+21%)	1223(+11%)	1711(+11%)	2198(+33%)
Elongation	200%(-45%)	140%(-57%)	77%(+10%)	143%(-24%)	82%(-52%)	118%(-52%)
Tensile stress, 100%, psi	637(+71%)	1093(+77%)	--	815(+33%)	--	1930(+206%)
Compression Set						
70 hrs/275°F	75%	75%	80%	66%	92%	97%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XIII - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-74	RAF-75	RAF-76	RAF-77	RAF-78	RAF-79
Fluorel KX-2150	100.0	--	--	100.0	100.0	75.0
Fluorel K-2140	--	70.0	100.0	--	--	--
Cyanacril LT3	--	30.0	--	--	--	25.0
FEF Black	25.0	--	--	25.0	25.0	60.0
MT Black	--	30.0	50.0	--	--	--
Maglite D	15.0	--	--	20.0	--	--
Calcium oxide	--	15.0	--	--	15.0	15.0
Maglite Y	--	--	15.0	--	--	--
Freon E3	10.0	--	--	--	--	--
FS 1265 silicone oil	--	--	10.0	--	--	--
TP-95	--	--	10.0	10.0	10.0	15.0
Tetramethyl guanidine	2.0	--	1.5	2.0	2.0	1.7
Diak No. 1	--	3.0	--	--	--	--
	152.0	148.0	186.5	157.0	152.0	191.7
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	24 hrs/ 250°F	16 hrs/ 300°F	24 hrs/ 212°F	48 hrs/ 250°F	48 hrs/ 250°F	24 hrs/ 250°F

TABLE XIV - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-74	RAF-75	RAF-76	RAF-77	RAF-78	RAF-79
Original Properties						
Shore A hardness	91	83	67	79	73	79
Tensile strength, psi	2452	1011	836	1886	1466	674
Elongation	108%	47%	367%	203%	250%	77%
Tensile stress, 100%, psi	2259	--	345	976	643	--
Temperature retraction	+10°F	--	-18°F	-10°F	-14°F	*
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	91	81(-2)	75(+8)	88 (+9)	83 (+10)	83 (+4)
Tensile strength, psi	2442(-5%)	957(-5%)	1184(+42%)	1231 (-35%)	2479 (+69%)	814 (+21%)
Elongation	83%(-23%)	60%(+27%)	250%(-32%)	137%(-33%)	163%(-35%)	42%(-46%)
Tensile stress, 100%, psi	--	--	621(+80%)	958 (-2%)	1910 (+197%)	--
Volume change	+2.1%	+15.4%	-6.0%	-6.9%	+0.3%	+4.6%
Air-Aged 96 hrs/275°F						
Shore A hardness	93(+2)	87(+4)	71(+4)	86 (+7)	83 (+10)	90 (+11)
Tensile strength, psi	2817(+15%)	1169(+15%)	945(+13%)	2061 (+9%)	1512 (+3%)	1159 (+72%)
Elongation	87%(-19%)	57%(+21%)	273%(-26%)	170%(+16%)	155%(-38%)	33%(-57%)
Tensile stress, 100%, psi	--	--	487(+41%)	1567 (+60%)	1165 (+81%)	--
Compression Set						
70 hrs/275°F	77%	44%	80%	79%	67%	84%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XV - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-80	RAF-81	RAF-82	RAF-83	RAF-84	RAQ-12
Kel F 5500	--	--	--	--	--	100.0
Fluorel KX-2150	75.0	--	--	--	--	--
Viton A-HV	--	75.0	100.0	--	--	--
Cyanacril LT3	25.0	25.0	--	--	--	--
Viton A	--	--	--	100.0	--	--
Viton B	--	--	--	--	100.0	--
FEF Black	60.0	42.5	40.0	20.0	20.0	40.0
Calcium oxide	--	15.0	--	--	15.0	--
Zinc oxide	--	--	--	--	--	10.0
Dyphos	--	--	--	--	--	10.0
Maglite D	15.0	--	20.0	--	--	--
Maglite Y	--	--	--	15.0	--	--
TP-95	15.0	10.0	20.0	--	--	10.0
Diak No. 4	--	2.0	--	--	2.5	--
Tetramethyl guanidine	1.7	--	1.5	--	--	--
Diak No. 1	--	--	--	1.3	--	3.0
	191.7	169.5	181.5	136.3	137.5	173.0
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 350°F	30 min/ 350°F	45 min/ 330°F
Secondary oven cure	24 hrs/ 250°F	24 hrs/ 275°F	24 hrs/ 250°F	--	--	24 hrs/ 212°F

TABLE XVI - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-80	RAF-81	RAF-82	RAF-83	RAF-84	RAQ-12
Original Properties						
Shore A hardness	80	70	71	78	81	84
Tensile strength, psi	1025	356	1709	2727	2009	1788
Elongation	80%	487%	310%	220%	160%	238%
Tensile stress, 100%, psi	--	299	547	714	1173	677
Temperature retraction	*	-15°F	-23°F	+6°F	+9°F	+3°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	85 (+5)	73 (+3)	91 (+20)	80 (+2)	82 (+1)	90(+6)
Tensile strength, psi	1123 (+9%)	652 (+83%)	2240 (+31%)	2890 (+6%)	1826 (-9%)	1554(-13%)
Elongation	60%(-25%)	167%(-66%)	137%(-56%)	183%(-17%)	133%(-17%)	213%(-11%)
Tensile stress, 100%, psi	--	624 (+109%)	1923 (+252%)	1036 (+45%)	1333 (+14%)	887(+31%)
Volume Change	-1.1%	+12.8%	-13.4%	+1.8%	+9.7%	-3.8%
Air-Aged 96 hrs/275°F						
Shore A hardness	84 (+4)	84 (+14)	78 (+7)	82 (+4)	86 (+5)	86(+2)
Tensile strength, psi	1177 (+15%)	758 (+118%)	1984 (+16%)	2668 (-2%)	1737 (-13%)	1703(-4%)
Elongation	47%(-41%)	240%(-51%)	170%(-45%)	160%(-27%)	137%(-14%)	205%(-14%)
Tensile stress, 100%, psi	--	758 (+153%)	1264 (+131%)	1290 (+81%)	1531 (+30%)	948(+40%)
Compression Set						
70 hrs/275°F	80%	97%	86%	65%	50%	82%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XVII - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-85	RAF-86	RAF-89	RAF-90	RAF-91	RAF-92
Viton A	--	--	--	--	100.0	95.0
Nordel 1070	--	--	--	--	--	5.0
Fluorel KX-2150	100.0	95.0	--	90.0	--	--
Butyl HT 1066	--	5.0	--	--	--	--
Fluorel K 2140	--	--	100.0	--	--	--
Cyanacril LT3	--	--	--	10.0	--	--
FEF Black	25.0	30.0	25.0	30.0	25.0	30.0
Calcium Oxide	15.0	15.0	15.0	--	--	--
Maglite D	--	--	--	15.0	--	--
Maglite Y	--	--	--	--	15.0	15.0
Diak No. 1	--	--	--	--	1.3	1.3
Flexol GPE	--	--	--	--	15.0	15.0
TP-95	10.0	10.0	10.0	--	--	--
Tetramethyl guanidine	2.0	2.0	2.0	2.0	--	--
	152.0	157.0	152.0	147.0	156.3	161.3
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 350°F	30 min/ 350°F
Secondary oven cure	48 hrs/ 212°F	24 hrs/ 250°F	24 hrs/ 250°F	24 hrs/ 250°F	--	--

TABLE XVIII - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-85	RAF-86	RAF-89	RAF-90	RAF-91	RAF-92
Original Properties						
Shore A hardness	69	74	71	93	66	56
Tensile strength, psi	1238	1169	1671	2181	1169	1233
Elongation	257%	177%	237%	111%	205%	430%
Tensile stress, 100%, psi	514	755	697	2104	406	184
Temperature retraction	-16°F	-14°F	-15°F	*	-10°F	-10°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	80 (+11)	79 (+5)	86 (+15)	88 (-5)	81 (+15)	64 (+8)
Tensile strength, psi	1354 (+9%)	944 (-19%)	2214 (+32%)	1899 (-13%)	1917 (+64%)	1468 (+19%)
Elongation	143% (-44%)	93% (-47%)	167%(-29%)	87%(-22%)	160%(-22%)	323%(-25%)
Tensile stress, 100%, psi	973 (+39%)	--	1471 (+111%)	--	1077 (+165%)	330 (+79%)
Volume change	-2.3%	+12.8%	-9.9%	+6.5%	-8.4%	+3.8%
Air-Aged 96 hrs/275°F						
Shore A hardness	82 (+13)	85 (+11)	76 (+5)	93 (0)	84 (+18)	72 (+16)
Tensile strength, psi	1450 (+17%)	1254 (+7%)	1822 (+9%)	2156 (-1%)	1776 (+52%)	1704 (+38%)
Elongation	127%(-50%)	100%(-43%)	163%(-31%)	75%(-32%)	155%(-24%)	333%(-22%)
Tensile stress, 100%, psi	1266 (+146%)	1254 (+66%)	1198 (+71%)	--	1065 (+162%)	430 (+134%)
Compression Set						
70 hrs/275°F	90%	81%	89%	86%	72%	76%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XIX - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-93	RAF-94	RAF-95	RAF-96	RAF-97	RAF-98
Viton A	100.0	--	100.0	95.0	95.0	--
Nordel 1070	--	--	--	5.0	5.0	--
Fluorel KX-2150	--	100.0	--	--	--	100.0
Calcium oxide	--	15.0	15.0	15.0	15.0	15.0
Maglite Y	15.0	--	--	--	--	--
FEF Black	30.0	35.0	20.0	32.5	32.5	25.0
Diak No. 1	1.3	--	1.3	1.3	1.3	--
Tetramethyl guanidine	--	2.0	--	--	--	2.0
Vistanex MM L100	5.0	--	--	--	--	--
Flexol EPO	--	--	--	15.0	--	--
Flexol GPE	15.0	10.0	--	--	15.0	--
TP 95	--	--	--	--	--	10.0
	156.3	162.0	136.3	163.8	163.8	152.0
Press cure	30 min/ 350°F	30 min/ 330°F	30 min/ 350°F	30 min/ 350°F	30 min/ 350°F	30 min/ 350°F
Secondary oven cure	--	--	--	--	--	--

TABLE XX - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-93	RAF-94	RAF-95	RAF-96	RAF-97	RAF-98
Original Properties						
Shore A hardness	58	76	73	77	71	73
Tensile strength, psi	1078	1105	1676	621	917	1124
Elongation	473%	167%	267%	295%	253%	200%
Tensile stress, 100%, psi	189	757	538	311	390	664
Temperature retraction	-13°F	-2°F	0°F	-3°F	-11°F	-12°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	71 (+13%)	84 (+8)	73	73 (-4)	77 (+6)	88 (+15)
Tensile strength, psi	1138 (+6%)	1246 (+13%)	1348 (-20%)	653 (+5%)	951 (+4%)	1324 (+18%)
Elongation	242%(-57%)	110%(-34%)	153%(-42%)	85%(-91%)	153%(-40%)	55%(-73%)
Tensile stress, 100%, psi	484 (+156%)	1164 (+53%)	776 (+44%)	--	688 (+76%)	--
Volume change	+7.5%	+.3%	+19.3%	+19.0%	+14.5%	+1.1%
Air-Aged 96 hrs/275°F						
Shore A hardness	75 (+17)	84 (+8)	80 (+7)	85 (+8)	87 (+16)	83 (+10)
Tensile strength, psi	1556 (+44%)	1246 (+13%)	1934 (+15%)	817 (+15%)	1089 (+19%)	1454 (+29%)
Elongation	327%(-31%)	110%(-34%)	210%(-21%)	170%(-42%)	160%(-37%)	120%(-40%)
Tensile stress, 100%, psi	469 (+148%)	1164 (+54%)	779 (-45%)	644 (+104%)	830 (+113%)	1269 (+91%)
Compression Set						
70 hrs/275°F	84%	81%	57%	72%	80%	100%

TABLE XXI - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-99	RAF-100	RAF-101	RAF-102	RAF-103	RAF-104
ECD-487	--	--	--	--	--	100.0
Fluorel KX 2150	100.0	--	--	--	90.0	--
Viton A-HV	--	100.0	--	--	--	--
Fluorel K 2141	--	--	90.0	--	--	--
Fluorel K 2140	--	--	--	90.0	--	--
Cyanacril LT 3	--	--	10.0	10.0	10.0	--
Natsyn	--	10.0	--	--	--	--
FEF Black	25.0	36.0	34.0	34.0	34.0	25.0
Calcium Oxide	15.0	--	--	--	--	--
Maglite D	--	20.0	15.0	15.0	15.0	--
Maglite Y	--	--	--	--	--	15.0
Diak No. 1	--	--	--	--	--	3.0
TP-95	10.0	20.0	--	--	15.0	--
Tetramethyl guanadine	2.0	1.5	2.0	2.0	2.0	--
PSD 75	--	0.3	--	--	--	--
	152.0	187.8	151.0	151.0	166.0	143.0
Press cure	30 min/ 350°F	30 min/ 350°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	48 hrs/ 250°F	24 hrs/ 250°F	24 hrs/ 250°F	24 hrs/ 250°F	24 hrs/ 250°F	24 hrs/ 400°F 24 hrs/ 450°F 24 hrs/ 500°F

TABLE XXII - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-99	RAF-100	RAF-101	RAF-102	RAF-103	RAF-104
Original Properties						
Shore A hardness	79	61	92	85	74	90
Tensile strength, psi	1537	1153	2013	2320	1542	1754
Elongation	175%	202%	72%	157%	160%	67%
Tensile stress, 100%, psi	935	--	--	1695	1137	--
Temperature retraction	-9°F	-25°F	*	-5°F	-17°F	-21°F
Aged 168 hrs/275°F						
Shore A hardness	84 (+5)	73 (+12)	89 (-3)	83 (-2)	87 (+13)	87 (-3)
Tensile strength, psi	1560 (+2%)	1020 (-11%)	1630 (-19%)	2053 (-11%)	1896 (+23%)	1488 (-15%)
Elongation	123%(-30%)	87%(-60%)	63%(-13%)	110%(-30%)	85%(-47%)	68%(+1%)
Tensile stress, 100%, psi	1314 (+40%)	--	--	1926 (+14%)	--	--
Volume change	+2.1%	-1.8%	+5.6%	+6.3%	+6.7%	+3.3%
Air-Aged 96 hrs/275°F						
Shore A hardness	87 (+8)	76 (+15)	94 (+2)	89 (+4)	83 (+9)	90 (0)
Tensile strength, psi	1764 (+15%)	1372 (+19%)	2012 (0)	2331 (+5%)	1862 (+17%)	1658 (-5%)
Elongation	125%(-29%)	117%(-42%)	53%(-26%)	100%(-36%)	90%(-44%)	65%(-3%)
Tensile stress, 100%, psi	1577 (+69%)	1155 (+99%)	--	2331 (+37%)	--	--
Compression Set						
70 hrs/275°F	77%	71%	53%	69%	84%	36%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XXIII - INGREDIENTS AND CURE SCHEDULES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-105	RAF-106	RAF-107	RAF-108
Fluorel KX 2146	--	--	20.0	--
ECD 487	100.0	100.0	80.0	100.0
FEF black	25.0	25.0	20.0	25.0
Maglite K	--	--	--	20.0
Maglite Y	15.0	15.0	15.0	--
Harflex 325	4.0	--	--	--
LD 227	--	5.0	--	--
Zinc Stearate	--	--	--	1.0
Diak No. 1	3.0	3.0	3.0	1.4
	147.0	148.0	138.0	147.4
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 300°F	30 min/ 330°F
Secondary oven cure	24 hrs/ 400°F	24 hrs/ 400°F	24 hrs/ 400°F	1 hr/ 300°F
	24 hrs/ 450°F	24 hrs/ 450°F	24 hrs/ 450°F	1 hr/ 350°F
	24 hrs/ 500°F	24 hrs/ 500°F	24 hrs/ 500°F	24 hrs/ 400°F

TABLE XXIV - PROPERTIES OF FLUOROELASTOMERIC COMPOUNDS AND BLENDS

	RAF-105	RAF-106	RAF-107	RAF-108
Original Properties				
Shore A hardness	88	84	87	80
Tensile strength, psi	1962	2107	1795	2386
Elongation	140%	163%	132%	277%
Tensile stress, 100%, psi	1455	1159	1344	767
Temperature retraction	-19°F	-17°F	-16°F	-15°F
Aged 168 hrs/275°F MIL-H-5606				
Shore A hardness	85 (-3)	83 (-1)	84 (-3)	79 (-1)
Tensile strength, psi	1869 (-5%)	2166 (+3%)	2109 (+18%)	2868 (+20%)
Elongation	133%(-5%)	163%(0)	143%(+8%)	270%(-3%)
Tensile stress, 100%, psi	1319 (-9%)	1103 (+5%)	1222 (-9%)	927 (-34%)
Volume change	+3.0%	+10.3%	+3.0%	+2.6%
Air-Aged 96 hrs/275°F				
Shore A hardness	87 (-1)	86 (+2)	87 (0)	81 (+1)
Tensile strength, psi	2081 (+6%)	1888 (-10%)	1941 (+8%)	2487 (+4%)
Elongation	130%(-7%)	140%(-14%)	130%(-2%)	260%(-6%)
Tensile stress, 100%, psi	1590 (+9%)	1249 (+8%)	1447 (+8%)	871 (+13%)
Compression Set				
70 hrs/275°F	28%	37%	31%	48%

TABLE XXV - INGREDIENTS AND CURE SCHEDULES OF EPICHLOROHYDRIN COMPOUNDS

	RAX-1	RAX-3	RAX-4	RAX-13	RAK-1	RAK-2
CHR rubber	100.0	--	--	100.0	--	--
CHR-X rubber (hydrin 200)	--	100.0	100.0	--	100.0	100.0
Agerite Resin D	1.0	1.0	--	1.0	--	--
NBC	--	--	1.0	--	1.0	1.0
Red lead	5.0	5.0	5.0	--	5.0	5.0
White lead	--	--	--	5.0	--	--
HAF Black	--	--	--	--	50.0	75.0
FEF Black	30.0	30.0	30.0	60.0	--	--
NA-22	1.5	1.5	1.5	--	--	--
TP-70 process oil	1.0	--	--	--	--	--
Dioctyl Sebacate	--	--	--	10.0	--	--
TP-95	--	--	--	--	5.0	10.0
Diak No. 1	--	--	--	0.8	0.8	0.8
	138.5	137.5	137.5	176.8	161.8	191.8
Press cure	45 min/ 310°F	45 min/ 310°F	45 min/ 310°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--	--

TABLE XXVI - PROPERTIES OF EPICHLOROHYDRIN COMPOUNDS

	RAX-1	RAX-3	RAX-4	RAX-13	RAK-1	RAK-2
Original Properties						
Shore A hardness	62-69	69	70	52	66	80
Tensile strength, psi	1727	1262	1724	1529	2000	611
Elongation	285%	210%	323%	353%	510%	210%
Tensile stress, 100%, psi	440	421	445	283	296	431
Temperature retraction	-7°F	-32°F	-43°F	-4°F	-42°F	-37°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	60-67	60 (-9)	64 (-6)	59(-7)	65(-1)	78(-2)
Tensile strength, psi	1893 (+10%)	861 (-32%)	1576 (-9%)	1282(-16%)	306(-84%)	198(-67%)
Elongation	230% (-19%)	160% (-24%)	253% (-22%)	160%(-55%)	293%(-43%)	10%(-95%)
Tensile stress, 100%, psi	614 (+40%)	366 (-13%)	389 (-13%)	613(+117%)	176(-40%)	--
Volume change	+9.3%	+10.0%	+10.0%	+4.9%	+5.5%	+2.8%
Air-Aged 96 hrs/275°F						
Shore A hardness	74-78	68 (-1)	69 (-1)	67 (+15)	72(+6)	94(+14)
Tensile strength, psi	1749 (+2%)	1249 (-1%)	1758 (+2%)	1610(+5%)	260(-87%)	602(-2%)
Elongation	160% (-44%)	195% (-7%)	230% (-29%)	150% (-58%)	187%(-63%)	10%(-95%)
Tensile stress, 100%, psi	921 (+109%)	478 (+14%)	547 (+23%)	913 (+222%)	252(-14%)	--
Compression Set						
70 hrs/275°F	52%	--	39%	74%	62%	88%

TABLE XXVII - INGREDIENTS AND CURE SCHEDULES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-3	RAK-4	RAK-5	RAK-6	RAK-7	RAK-8
Hydrin 200	100.0	100.0	100.0	100.0	100.0	100.0
FEF Black	75.0	75.0	--	--	--	75.0
HAF Black	--	--	50.0	75.0	75.0	--
Red lead	5.0	5.0	5.0	5.0	--	5.0
Dyphos	--	--	--	--	10.0	--
NBC	1.0	1.0	1.0	1.0	1.0	1.0
TP-95	10.0	10.0	5.0	10.0	10.0	10.0
Diak No. 1	1.6	1.6	.8	--	--	--
NA-22	--	--	--	2.0	2.0	--
Piperazine	--	--	--	--	--	0.8
	192.6	192.6	161.8	193.0	198.0	191.8
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	24 hrs/ 212°F	24 hrs/ 212°F	24 hrs/ 212°F	24 hrs/ 212°F	24 hrs/ 212°F

TABLE XXVIII - PROPERTIES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-3	RAK-4	RAK-5	RAK-6	RAK-7	RAK-8
Original Properties						
Shore A hardness	83	85	74	93	91	70
Tensile strength, psi	1949	1906	2009	1738	1828	672
Elongation	187%	140%	383%	95%	110%	340%
Tensile stress, 100%, psi	1323	1502	486	--	1705	233
Temperature retraction	-47°F	-45°F	-40°F	-45°F	*	-29°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	90(+7)	88 (+3)	71 (-3)	93 (0)	93 (+2)	67 (-3)
Tensile strength, psi	1696(-13%)	1696 (-11%)	1054 (-47%)	1319 (-24%)	1632 (-11%)	289 (-57%)
Elongation	127%(-32%)	123%(-12%)	385%(+1%)	88%(-7%)	102%(-7%)	167%(-51%)
Tensile stress, 100%, psi	1484(+12%)	1466 (-2%)	335 (-31%)	--	1600 (-6%)	259 (+11%)
Volume change	-0.2%	+2.1%	+6.0%	+0.2%	-0.3%	+3.2%
Air-Aged 96 hrs/275°F						
Shore A hardness	92(+9)	90 (+5)	74 (0)	94 (+1)	94 (+3)	82 (+12)
Tensile strength, psi	1859(-4%)	1740 (-8%)	461 (-77%)	1715 (-1%)	1648 (-9%)	312 (-54%)
Elongation	105%(-43%)	110%(-21%)	220%(-42%)	60%(-36%)	80%(-27%)	57% (-83%)
Tensile stress, 100%, psi	1776(+34%)	1642 (+9%)	346 (-29%)	--	--	--
Compression Set						
70 hrs/275°F	55%	56%	62%	69%	73%	88%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XXIX - INGREDIENTS AND CURE SCHEDULES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-9	RAK-10	RAK-11	RAK-12	RAK-13	RAK-14
Hydrin 200	100.0	100.0	100.0	100.0	100.0	100.0
FEF Black	75.0	75.0	75.0	75.0	--	--
SAF Black	--	--	--	--	50.0	--
HAF Black	--	--	--	--	--	90.0
Dyphos	--	5.0	10.0	10.0	10.0	10.0
NBC	1.0	1.0	1.0	1.0	1.0	1.0
TP 95	10.0	10.0	10.0	10.0	10.0	10.0
NA-22	2.5	1.6	1.6	--	2.5	1.6
TETA	--	--	--	1.2	--	--
Red lead	5.0	--	--	--	5.0	5.0
Diak No. 1	--	--	--	--	--	1.0
	193.5	192.6	197.6	197.6	178.5	208.6
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--	--

TABLE XXX - PROPERTIES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-9	RAK-10	RAK-11	RAK-12	RAK-13	RAK-14
Original Properties						
Shore A hardness	86	82	85	94	76	88
Tensile strength, psi	1998	1849	1621	1655	2356	1429
Elongation	123%	170%	115%	65%	242%	103%
Tensile stress, 100%, psi	1661	1229	1484	--	765	1394
Temperature retraction	-50°F	-47°F	-44°F	*	-49°F	*
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	87 (+1)	86 (+4)	89 (+4)	93 (-1)	81 (+5)	93 (+5)
Tensile strength, psi	1625 (-19%)	1796 (-3%)	1620 (0)	1175 (-29%)	2162 (-8%)	1176 (-17%)
Elongation	93%(-24%)	128%(-25%)	90%(-21%)	58%(-11%)	173%(-28%)	57%(-44%)
Tensile stress, 100%, psi	--	1493 (+21%)	--	--	1027 (+34%)	--
Volume change	-0.5%	-0.8%	+.01%	-.01%	+.03%	+1.0%
Air-Aged 96 hrs/275°F						
Shore A hardness	92 (+6)	89 (+7)	92 (+7)	94	88 (+12)	96 (+8)
Tensile strength, psi	1746 (-13%)	1755 (-5%)	1683 (+4%)	970 (-41%)	1840 (-22%)	1407 (-2%)
Elongation	78%(-37%)	123%(-27%)	83%(-28%)	20%(-69%)	122%(-49%)	55%(-46%)
Tensile stress, 100%, psi	--	1615 (+31%)	--	--	1469 (+92%)	--
Compression Set						
70 hrs/275°F	60%	77%	69%	73%	74%	85%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XXXI - INGREDIENTS AND CURE SCHEDULES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-15	RAK-16	RAK-17	RAK-18	RAK-19	RAK-20
Hydrin 200	100.0	100.0	100.0	100.0	100.0	100.0
FEF Black	75.0	75.0	75.0	--	75.0	37.5
HAF Black	--	--	--	75.0	--	--
SAF Black	--	--	--	--	--	25.0
Red lead	5.0	5.0	--	--	5.0	--
Calcium oxide	--	--	10.0	10.0	--	--
Dyphos	--	--	--	--	--	5.0
Agerite Resin D	--	--	--	--	--	1.0
NBC	1.0	1.0	1.0	1.0	1.0	--
TP 95	10.0	10.0	10.0	10.0	10.0	5.0
Varox	6.5	--	--	--	--	--
Tetramethyl guandine	--	1.5	1.5	--	--	--
NA-22	--	--	--	2.0	--	--
Diethyl Thiorea	--	--	--	--	2.5	--
PND-70	--	--	--	--	--	2.2
	197.5	192.5	197.5	198.0	193.5	175.7
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--	--

TABLE XXXII - PROPERTIES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-15	RAK-16	RAK-17	RAK-18	RAK-19	RAK-20
Original Properties						
Shore A hardness		74	87	99	75	78
Tensile strength, psi		1489	1518	983	1482	2377
Elongation		243%	137%	5%	250%	247%
Tensile stress, 100%, psi		703	1248	--	672	1013
Temperature retraction		-36°F	-36°F	--	-30°F	-44°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness		78 (+4)	92 (+5)	100	84 (+9)	83 (+5)
Tensile strength, psi	DID	1260 (-15%)	948 (-37%)	*	1464 (-1%)	2080 (-13%)
Elongation	NOT	127%(-47%)	43%(-68%)	*	150%(-40%)	145%(-41%)
Tensile stress, 100%, psi	CURE	992 (+41%)	--	*	1028 (+53%)	1487 (+47%)
Volume change		+1.7%	+4.3%	-4.3%	+1.0%	+4.4%
Air-Aged 96 hrs/275°F						
Shore A hardness		91 (+7)	97 (+10)	*	89 (+14)	89 (+11)
Tensile strength, psi		1588 (+6%)	1705 (+12%)	*	1499 (+1%)	2206 (-7%)
Elongation		92% (-62%)	35%(-74%)	*	117%(-53%)	123%(-50%)
Tensile stress, 100%, psi		--	--	--	1398 (+108%)	1781 (+76%)
Compression Set						
70 hrs/275°F		81%	86%	74%	70%	66%

* Test could not be made because properties of specimen were deficient.

TABLE XXXIII - INGREDIENTS AND CURE SHCEDULES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-21	RAK-22	RAK-23	RAK-24
Hydrin 200	100.0	100.0	100.0	100.0
SAF black	50.0	50.0	50.0	50.0
Zinc stearate	1.0	1.0	1.0	1.0
PRD 90	5.6	5.6	5.6	5.6
NBC	1.0	1.0	1.0	1.0
TP 70	1.0	1.0	1.0	1.0
TETA	2.0	2.0	--	--
MBTS	3.0	3.0	--	--
Piperazine	--	--	0.75	--
Trimene base	--	--	--	2.5
	163.6	163.6	159.35	161.1
Press cure	30 min/ 300°F	30 min/ 300°F	30 min/ 300°F	30 min/ 300°F
Secondary oven cure	--	24 hrs/ 300°F	--	24 hrs/ 300°F

TABLE XXXIV - PROPERTIES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-21	RAK-22	RAK-23	RAK-24
Original Properties				
Shore A hardness	84	89	64	84
Tensile strength, psi	2696	2413	1787	796
Elongation	517%	257%	709%	227%
Tensile stress, 100%, psi	599	990	249	608
Temperature retraction	-27°F	-34°F	-26°F	-31°F
Aged 168 hrs/275°F MIL-H-5606				
Shore A hardness	86 (+2)	81 (-8)	65 (+1)	76 (-8)
Tensile strength, psi	2062 (-23%)	572 (-76%)	1085 (-39%)	358 (-55%)
Elongation	227% (-56%)	120% (-53%)	420% (-41%)	80% (-65%)
Tensile stress, 100%, psi	974 (-63%)	505 (-49%)	301 (+21%)	--
Volume change	+8.4%	+9.8%	+10.6%	+10.8%
Air-Aged 96 hrs/275°F				
Shore A hardness	89 (+5)	91 (+2)	80 (+16)	86 (+2)
Tensile strength, psi	2087 (-22%)	1011 (-58%)	916 (+49%)	516 (-35%)
Elongation	243% (-53%)	163% (-37%)	330% (-54%)	80% (-65%)
Tensile stress, 100%, psi	1057 (+76%)	847 (-14%)	428 (+72%)	--
Compression Set				
70 hrs/275°F	83%	58%	75%	67%

TABLE XXXV - INGREDIENTS AND CURE SCHEDULES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-25	RAK-26	RAK-27	RAK-28
Hydrin 200	100.0	100.0	100.0	100.0
SAF black	50.0	--	--	25.0
FEF black	--	75.0	--	37.5
HAF black	--	--	75.0	--
PRD 90	5.6	5.6	5.6	5.6
NBC	1.0	1.0	1.0	1.0
TP 95	5.0	5.0	5.0	5.0
PND 70	2.0	2.0	2.0	2.0
	163.6	188.6	188.6	176.1
Press cure	30 min/ 300°F	30 min/ 300°F	30 min/ 300°F	30 min/ 300°F
Secondary oven cure	24 hrs/ 300°F	24 hrs/ 300°F	24 hrs/ 300°F	24 hrs/ 250°F

TABLE XXXVI - PROPERTIES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-25	RAK-26	RAK-27	RAK-28
Original Properties				
Shore A hardness	82	91	90	82
Tensile strength, psi	2117	1728	2152	2686
Elongation	193%	137%	133%	247%
Tensile stress, 100%, psi	892	1422	1837	1016
Temperature retraction	-42°F	*	*	-41°F
Aged 168 hrs/275°F MIL-H-5606				
Shore A hardness	75 (-7)	86 (-5)	89 (-1)	75 (-7)
Tensile strength, psi	2425 (+14%)	1315 (-24%)	1661 (-23%)	1874 (-30%)
Elongation	272%(+41%)	150%(+9%)	130%(-2%)	217%(-12%)
Tensile stress, 100%, psi	751 (-16%)	1061 (-25%)	1460 (-21%)	810 (-20%)
Volume Change	+7.2%	+6.4%	+6.5%	+7.0%
Air-Aged 96 hrs/275°F				
Shore A hardness	84 (+2)	93 (+2)	95 (+5)	81 (-1)
Tensile strength, psi	2664 (+26%)	1451 (-16%)	1776 (-17%)	2488 (-7%)
Elongation	250%(+29%)	117%(-15%)	103%(-23%)	215%(-13%)
Tensile stress, 100%, psi	952 (+6%)	1290 (-9%)	1776 (-3%)	1218 (+19%)
Compression Set				
70 hrs/275°F	45%	39%	50%	53%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XXXVII - INGREDIENTS AND CURE SCHEDULES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-29	RAK-31
Hydrin 200	100.0	100.0
SAF black	25.0	25.0
FEF black	37.5	37.5
PRD 90	5.6	5.6
NBC	1.0	1.0
TP 95	5.0	5.0
Thiate E	1.4	--
PND 70	--	2.0
Permalux	--	0.5
	175.5	176.6
Press cure	45 min/ 300°F	30 min/ 300°F
Secondary oven cure	24 hrs/ 250°F	24 hrs/ 250°F

TABLE XXXVIII - PROPERTIES OF EPICHLOROHYDRIN COMPOUNDS

	RAK-29	RAK-31
Original Properties		
Shore A hardness	75	80
Tensile strength, psi	1949	2592
Elongation	357%	246%
Tensile stress, 100%, psi	535	985
Temperature retraction	-36°F	-41°F
Aged 168 hrs/275°F MIL-H-5606		
Shore A hardness	70 (-5)	75 (-5)
Tensile strength, psi	1214 (-38%)	1804 (-32%)
Elongation	265%(-26%)	227%(-8%)
Tensile stress, 100%, psi	460%(-14%)	745 (-24%)
Volume change	+6.9%	+6.6%
Air-Aged 96 hrs/275°F		
Shore A hardness	74 (-1)	80
Tensile strength, psi	1810 (-7%)	2241 (-14%)
Elongation	300%(-16%)	192%(-22%)
Tensile stress, 100%, psi	671 (+25%)	1054 (+7%)
Compression Set		
70 hrs/275°F	59%	54%

TABLE XXXIX - INGREDIENTS AND CURE SCHEDULES OF EXPERIMENTAL POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-6	RAA-7	RAA-9	RAA-10	RAA-11	RAA-12	RAA-13
Thiacril 44	75.0	--	--	--	--	85.0	85.0
Cyanacril HTS-1	--	--	5.0	--	--	--	--
Cyanacril	--	75.0	100.0	85.0	85.0	--	--
Thiacril 55	--	--	--	--	--	--	--
Butyl HT-1066	25.0	25.0	--	15.0	15.0	15.0	15.0
Stearic acid	1.0	2.0	2.0	2.0	2.0	1.0	0.5
FEF Black	62.5	35.0	35.0	35.0	35.0	52.5	52.5
HAF Black	7.5	7.5	--	--	--	--	--
SRF Black	--	27.5	35.0	35.0	35.0	--	--
TP-95	--	--	5.0	--	--	--	--
Dyphos	5.0	--	--	--	--	5.0	5.0
Red lead	--	--	--	--	--	--	--
NA-22	2.0	0.2	--	0.2	.2	2.0	1.5
Ammonium Benzoate	--	4.0	4.0	4.0	4.0	--	--
Neozone D	--	2.0	2.0	2.0	2.0	--	--
Vulklor	--	--	--	--	--	--	0.5
HTS-1	--	--	--	--	5.0	--	--
	188.0	178.2	188.0	178.2	183.2	160.5	161.0
Press cure	12 min/ 370°F	8 min/ 332°F	8 min/ 330°F	8 min/ 330°F	8 min/ 330°F	12 min/ 370°F	8 min/ 330°F
Secondary oven cure	24 hrs/ 325°F	24 hrs/ 325°F	24 hrs/ 325°F	24 hrs/ 325°F	24 hrs/ 325°F	24 hrs/ 325°F	24 hrs/ 212°F

TABLE XL - PROPERTIES OF EXPERIMENTAL POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-6	RAA-7	RAA-9	RAA-10	RAA-11	RAA-12	RAA-13
Original Properties							
Shore A hardness	85	69	67	72	80	84	79
Tensile strength, psi	1767	1325	1462	1465	1487	1626	1850
Elongation	75%	220%	260%	280%	250%	100%	180%
Tensile stress, 100%, psi	--	721	539	540	674	1626	795
Temperature retraction	--	--	-17°F	+15°F	+14°F	+1°F	-1°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	68 (-7)	40 (-29)	71 (+4)	45 (-27)	48 (-32)	63 (-21)	54 (-25)
Tensile strength, psi	774 (-55%)	340 (-74%)	1309 (-10%)	658 (-55%)	720 (-51%)	778 (-52%)	876 (-52%)
Elongation	80%(+6%)	120%(-45%)	260%(0)	175%(-37)	165%(-34%)	80%(-20%)	160%(-11%)
Tensile stress 100%, psi	--	298 (-59%)	439 (-18%)	261 (-52%)	381 (-58%)	--	485 (-39%)
Volume change	+41.9%	+57.3%	+10.9%	+55.6%	+54.9%	+36.2%	+41.2%
Air-Aged 96 hrs/275°F							
Shore A hardness	90 (+5)	80 (+11)	80 (+13)	80 (+8)	80 (0)	84 (0)	79 (0)
Tensile strength, psi	1900 (+7%)	1256 (-5%)	1685 (-15%)	1515 (+3%)	1570 (+5%)	1739 (+1%)	1972 (+7%)
Elongation	80%(+6%)	180%(-18%)	140%(-46%)	200%(-28%)	210%(-16%)	100%(0)	210%(+16%)
Tensile stress 100%, psi	80%(+6%)	783 (+8%)	658 (+22%)	803 (+47%)	865 (+22%)	1739 (+7%)	775 (-2%)
Compression Set							
70 hrs/275°F	30%	29%	19%	28%	25%	30%	30%

TABLE XLI - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-14	RAA-18	RAA-20	RAA-23	RAA-24	RAA-25	RAA-26
Hycar 4021	--	--	100.0	--	--	--	--
Cyanacryl	--	--	--	50.0	--	50.0	85.0
Paracril 18-80	--	--	--	50.0	--	--	--
Dynagen XP 139	--	--	--	--	--	50.0	--
Butyl HT 1066	15.0	--	--	--	--	--	--
Thiacril 55	85.0	100.0	--	--	100.0	--	--
Nordel 1070	--	--	--	--	--	--	15.0
SAF Black	--	--	--	--	--	--	7.5
FEF Black	60.0	60.0	65.0	50.0	60.0	17.5	30.0
SRF Black	--	--	--	17.5	--	17.5	30.0
Stearic acid	1.0	1.0	1.0	2.0	1.0	2.0	0.5
TP 95	--	15.0	25.0	25.0	25.0	--	--
NA 22	2.0	2.0	2.0	--	2.0	--	--
Red lead	5.0	5.0	5.0	--	5.0	--	--
SP 1055 Resin	--	--	--	12.0	--	--	--
Di Cup 40C	--	--	--	--	--	8.0	9.0
Dioctyl Sebacate	--	--	--	--	--	--	--
	168.0	173.0	198.0	206.5	193.0	145.0	187.0
Press cure	8 min/ 330°F	8 min/ 330°F	30 min/ 400°F	30 min/ 400°F	30 min/ 400°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	24 hrs/ 212°F	24 hrs/ 212°F	--	--	--	--	--

TABLE XLII - PROPERTIES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-14	RAA-18	RAA-20	RAA-23	RAA-24	RAA-25	RAA-26
Original Properties							
Shore A hardness	74	61	61	72	55	73	64
Tensile strength, psi	1465	1134	1246	1183	1160	779	794
Elongation	370%	510%	280%	100%	350%	80%	115%
Tensile stress, 100%, psi	466	173	337	1183	275	--	671
Temperature retraction	-7°F	-28°F	-34°F	*	-44°F	*	-12°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	45 (-29)	51 (-10)	71 (+10)	71 (-1)	52 (-3)	57 (-16)	25 (-39)
Tensile strength, psi	848 (-44%)	1279 (+13%)	1105 (-11%)	417 (-64%)	918 (-20%)	186 (-76%)	256 (-67%)
Elongation	200%(-46%)	330 (-35%)	170%(-39%)	40%(-60%)	180%(-48%)	38%(-52%)	160%(+39%)
Tensile stress, 100%, psi	277 (-40%)	222 (+28%)	587 (+74%)	--	413 (+50%)	--	144 (-78%)
Volume change	+56.6%	+8.9%	+2.0%	+17.1%	+9.9%	+46.1%	+75.7%
Air-Aged 96 hrs/275°F							
Shore A hardness	79 (+5)	75 (+14)	74 (+13)	96 (+24)	74 (+19)	78 (+5)	77 (+13)
Tensile strength, psi	1880 (+28%)	1661 (+36%)	1251 (+1%)	**	1590 (+37%)	452 (-42%)	511 (-36%)
Elongation	170%(-54%)	270%(-47%)	140%(-50%)	**	245%(-30%)	50%(-37%	250%(+115%)
Tensile stress, 100%, psi	944 (+100%)	633 (+266%)	920 (+170%)	**	634 (+131%)	--	384 (-43%)
Compression Set							
70 hrs/275°F	85%	91%	72%	50%	81%	**	57%

** Test could not be made because properties of specimen were deficient.
* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE XLIII - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS

	RAA-27	RAA-28	RAA-29	RAA-30	RAA-31	RAA-32	RAA-33
Hycar 4021	--	--	100.0	100.0	--	--	--
Thiacril 55	100.0	100.0	--	--	100.0	--	--
Paracril OHT	--	--	--	--	--	100.0	100.0
FEF Black	60.0	60.0	65.0	65.0	65.0	65.0	65.0
Stearic acid	1.0	1.0	1.0	1.0	1.0	1.0	1.0
TP-95	25.0	25.0	25.0	25.0	25.0	25.0	--
TETA	--	--	2.0	--	--	--	--
MBTS	--	2.0	1.5	--	--	--	--
Trimene base	--	--	--	3.0	3.0	3.0	--
Sulfur	--	--	--	0.5	0.5	0.5	--
Dyphos	5.0	--	--	--	--	--	--
Diak No. 1	2.0	--	--	--	--	--	--
Triethylene Tetramine	--	1.5	--	--	--	--	--
Di Cup 40C	--	--	--	--	--	--	6.5
	193.0	189.5	194.5	194.5	194.5	194.5	172.5
Press cure	60 min/ 400°F	60 min/ 400°F	30 min/ 400°F	30 min/ 400°F	30 min/ 400°F	75 min/ 400°F	60 min/ 330°F
Secondary oven cure	--	--	--	--	--	--	24 hrs/ 300°F

TABLE XLIV - PROPERTIES OF POLYACRYLATE COMPOUNDS

	RAA-27	RAA-28	RAA-29	RAA-30	RAA-31	RAA-32	RAA-33
Original Properties							
Shore A hardness	60	49	64	69	53	59	76
Tensile strength, psi	1001	999	937	1203	969	408	1377
Elongation	263%	430%	167%	320%	320%	440%	253%
Tensile stress, 100%, psi	230	154	464	362	211	128	561
Temperature retraction	-42°F	-44°F	-34°F	-32°F	-48°F	-36°F	+5°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	57 (-3)	53 (+4)	66 (+2)	84 (+15)	64 (+11)	64 (-13)	82 (+6)
Tensile strength, psi	787 (-21%)	923 (-7%)	1175 (+25%)	1535 (+27%)	1044 (+8%)	482 (+18%)	725 (-47%)
Elongation	248%(-8%)	327%(-24%)	185%(+11%)	220%(-31%)	240%(-25%)	270%(-39%)	177%(-30%)
Tensile stress, 100%, psi	237 (+3%)	196 (+27%)	524 (+12%)	705 (+94%)	334 (+59%)	161 (+26%)	279 (-50%)
Volume change	+9.8%	+8.6%	+37.9%	-0.3%	+4.5%	+18.4%	+26.6%
Air-Aged 96 hrs/275°F							
Shore A hardness	79 (+19)	69 (+20)	79 (+15)	73 (+4)	70 (+17)	79 (+20)	69 (-7)
Tensile strength, psi	1149 (+14%)	978 (-2%)	1024 (+9%)	1591 (+32%)	1353 (+40%)	901 (+121%)	1329 (-4%)
Elongation	190%(-27%)	300%(-30%)	130%(-22%)	180%(-56%)	210%(-34%)	220%(-50%)	217%(-14%)
Tensile stress 100%, psi	558 (+142%)	307 (+99%)	755 (+63%)	607 (+67%)	525 (+156%)	400 (+212%)	593 (+6%)
Compression Set							
70 hrs/275°F	67%	42%	42%	66%	73%	94%	31%

TABLE XLV - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS

	RAA-35	RAA-36	RAA-37	RAA-38	RAA-39	RAA-40	RAA-41
Hycar 2121 x 58	--	--	--	--	100.0	--	--
Hycar 2121 x 61	--	--	--	--	--	100.0	--
Hycar 2121 x 60	--	--	--	--	--	--	100.0
Thiacril 55	100.0	100.0	100.0	100.0	--	--	--
FEF Black	90.0	90.0	90.0	60.0	65.0	65.0	65.0
Stearic acid	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Di Cup 40C	--	--	--	--	--	--	--
TP-95	25.0	25.0	15.0	--	10.0	10.0	10.0
TETA	--	1.5	1.5	1.5	--	--	--
MBTS	--	2.0	2.0	2.0	--	--	--
ESEN	--	--	--	--	1.5	1.5	1.5
Dyphos	5.0	--	--	--	4.0	--	2.0
Sulfur	--	--	--	--	--	1.5	--
Diethyl Thiourea	2.0	--	--	--	--	--	--
Harflex 330	--	--	10.0	--	--	--	--
Dioctyl Sebacate	--	--	--	25.0	--	--	--
	223.0	219.5	219.5	189.5	182.5	179.0	179.5
Press cure	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	24 hrs/ 212°F	24 hrs/ 212°F	24 hrs/ 212°F

TABLE XLVI - PROPERTIES OF POLYACRYLATE COMPOUNDS

	RAA-35	RAA-36	RAA-37	RAA-38	RAA-39	RAA-40	RAA-41
Original Properties							
Shore A hardness	66	65	55	50	73	60	65
Tensile strength, psi	830	542	520	974	1521	1165	1095
Elongation	136%	410%	457%	437%	200%	205%	170%
Tensile stress, 100%, psi	453	194	146	164	786	570	614
Temperature retraction	-43°F	-37°F	-20°F	-25°F	-11°F	-28°F	-43°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	76 (+10)	68 (+3)	55 (0)	56 (+6)	69 (-4)	45 (+15)	49 (-16)
Tensile strength, psi	1032 (+24%)	403 (-26%)	257 (-50%)	888 (-10%)	1379 (-9%)	858 (-26%)	727 (-34%)
Elongation	148%(+9%)	397%(-3%)	473%(+4%)	400% (-9%)	200%(0)	340%(+66%)	153%(-10%)
Tensile stress, 100%, psi	768 (+69%)	190 (-2%)	97 (-34%)	197 (+20%)	740 (-8%)	188 (-67%)	430 (-30%)
Volume change	+7.4%	+7.9%	+11.5%	+6.4%	+5.5%	+10.2%	+27.6%
Air-Aged 96 hrs/275°F							
Shore A hardness	85 (+19)	84 (+19)	73 (+18)	75 (+25)	79 (+6)	70 (+10)	72 (+7)
Tensile strength, psi	988 (+19%)	573 (+6%)	495 (-5%)	1029 (+6%)	1593 (+5%)	1438 (+23%)	1215 (+11%)
Elongation	95%(-30%)	350%(-15%)	397%(-13%)	320%(-27%)	177%(-11%)	190%(-7%)	160%(-6%)
Tensile stress 100%, psi	--	402 (+107%)	269 (+84%)	360 (+119%)	888 (+13%)	741 (+30%)	729 (+19%)
Compression Set							
70 hrs/275°F	52%	44%	53%	48%	37%	32%	32%

TABLE XLVII - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS AND BLENDS

Ingredients	RAA-42	RAA-43	RAA-44	RAA-45	RAA-46	RAA-47
Cyanacril	--	--	--	50.0	80.0	--
Thiacril 55	--	100.0	66.6	--	--	66.6
Cyanacril LT3	--	--	33.3	50.0	20.0	33.3
Thiacril 76	100.0	--	--	--	--	--
Stearic acid	1.0	1.0	1.0	2.0	2.0	1.0
FEF Black	85.0	90.0	60.0	17.5	20.0	60.0
SRF Black	--	--	--	17.5	20.0	--
Ivory beads	--	--	--	3.0	3.0	--
Pot. Stearate	--	--	--	0.5	0.5	--
Sulfur	--	--	--	0.3	0.3	--
Neozone D	--	--	--	2.0	2.0	--
TP-95	25.0	15.0	10.0	--	--	10.0
Freon E3	--	10.0	--	--	--	--
Agerite Resin D	1.5	--	--	--	--	--
Diak No. 1	1.0	--	--	--	--	--
TETA	--	1.5	1.5	--	--	1.5
MBTS	--	2.0	2.0	--	--	2.0
	213.5	219.5	174.4	142.8	147.8	174.4
Press cure	60 min/ 400°F	60 min/ 400°F	60 min/ 400°F	30 min/ 330°F	30 min/ 332°F	30 min/ 330°F
Secondary oven cure	--	--	--	24 hrs/ 300°F	--	16 hrs/ 300°F

TABLE XLVIII - PROPERTIES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-42	RAA-43	RAA-44	RAA-45	RAA-46	RAA-47
Original Properties						
Shore A hardness	55	79	50	45	56	54
Tensile strength	661	923	485	795	1091	499
Elongation	450%	203%	250%	213%	223%	230%
Tensile stress, 100%, psi	143	525	223	226	398	260
Temperature retraction	-27°F	-25°F	-29°F	+2°F	+3°F	-22°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	70 (+15)	72 (-7)	39 (-11)	33 (-12)	44 (-12)	40 (-14)
Tensile strength, psi	807 (+22%)	783 (-15%)	407 (-16%)	343 (-57%)	539 (-51%)	369 (-26%)
Elongation	277%(-38%)	240%(+18%)	240%(-4%)	155%(-22%)	173%(-22%)	190%(-17%)
Tensile stress, 100%, psi	294 (+106%)	358 (-32%)	194 (-13%)	138 (-39%)	239 (-40%)	220 (-15%)
Volume change	-0.6%	+10.6%	+23.7%	+35.2%	+34.2%	+27.6%
Air-Aged 96 hrs/275°F						
Shore A hardness	73 (+18)	85 (+6)	63 (+13)	56 (+11)	75 (+19)	56 (+2)
Tensile strength, psi	941 (+42%)	762 (-18%)	643 (+33%)	959 (+21%)	1275 (+16%)	612 (+23%)
Elongation	277%(-38%)	140%(-31%)	245%(-2%)	190%(-11%)	120%(-46%)	220%(-4%)
Tensile stress, 100%, psi	437 (+206%)	703 (+34%)	352 (+58%)	412 (+82%)	1013 (+154)	362 (+39%)
Compression Set						
70 hrs/275°F	77%	47%	59%	32%	43%	59%

TABLE XLIX - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-48	RAA-49	RAA-50	RAA-51	RAA-52
Hycar 4021	--	--	--	80.0	100.0
Thiacril 55	85.0	--	66.6	--	--
Cyanacril LT3	15.0	--	33.3	20.0	--
Thiacril 76	--	100.0	--	--	--
Stearic acid	1.0	1.0	1.0	1.0	1.0
FEF Black	--	85.0	60.0	--	--
SAF Black	40.0	--	--	40.0	50.0
TP-95	--	25.0	10.0	15.0	25.0
Dyphos	5.0	--	--	--	--
NA-22	3.0	--	--	2.0	2.0
Agerite Resin D	--	1.5	--	--	--
Diak No. 1	--	2.0	--	--	--
TETA	--	--	1.5	--	--
MBTS	--	--	2.0	--	--
Red Lead	--	--	--	5.5	5.0
	149.0	214.5	174.4	163.5	183.0
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 400°F	30 min/ 400°F
Secondary oven cure	16 hrs/ 300°F	24 hrs/ 212°F	24 hrs/ 212°F	-- --	-- --

TABLE L - PROPERTIES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-48	RAA-49	RAA-50	RAA-51	RAA-52
Original Properties					
Shore A hardness	69	70	51	55	58
Tensile strength, psi	1293	1337	497	1268	1744
Elongation	180%	180%	295%	437%	370%
Tensile stress, 100%, psi	581	640	188	225	258
Temperature retraction	-6°F	-30°F	-27°F	-24°F	-31°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	49 (-20)	73 [illegible]3)	35 (-16)	56 (+1)	70 (+12)
Tensile strength, psi	664 (-49%)	1328 [illegible]-1%)	285 (-43%)	858 (-32%)	1308 (-25%)
Elongation	140%(-22%)	215%(+19%)	21[illegible]%(-28%)	260%(-40%)	230%(-38%)
Tensile stress, 100%, psi	388 (-33%)	560 (-12%)	155 (-18%)	327 (+45%)	429 (+66%)
Volume change	+30.4%	+0.5%	+27.1%	+11.8%	+14.9%
Air-Aged 96 hrs/275°F					
Shore A hardness	76 (+7)	78 (+8)	61 (+10)	74 (+19)	76 (+18)
Tensile strength, psi	1070 (17%)	1280 (-4%)	630 (+27%)	1747 (+38%)	1798 (+3%)
Elongation	133%(-26%)	165%(-8%)	273%(-7%)	282 (-36%)	245%(+117%)
Tensile stress, 100%, psi	749 (+29%)	790 (+23%)	315 (+66%)	582 (+158%)	561 (+117)
Compression Set					
70 hrs/275°F	59%	48%	73%	68%	71%

TABLE LI - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-53	RAA-54	RAA-55	RAA-56
Cyanacril	20.0	--	--	--
Cyanacril LT3	80.0	--	--	--
Thiacril 55	--	100.0	100.0	--
Hycar 2121X38	--	--	--	100.0
Stearic acid	2.0	1.0	1.0	1.0
Ivory beads	3.0	--	--	--
Pot. Stearate	0.5	--	--	--
Neozone D	2.0	--	--	--
FEF Black	80.0	60.0	90.0	65.0
Sulfur	0.3	--	--	0.9
NA-22	--	2.0	2.0	--
Red lead	--	5.0	5.0	--
Igepol CO-630	--	25.0	10.0	--
TP-95	--	--	15.0	10.0
TETA	--	--	--	1.5
	187.8	193.0	223.0	178.4
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 400°F	30 min/ 330°F
Secondary oven cure	24 hrs/ 300°F	24 hrs/ 300°F	--	24 hrs/ 212°F

TABLE LII - PROPERTIES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-53	RAA-54	RAA-55	RAA-56
Original Properties				
Shore A hardness	86	62	70	64
Tensile strength, psi	1153	1238	923	1195
Elongation	123%	275%	383%	413%
Tensile stress, 100%, psi	916	375	327	266
Temperature retraction	-11°F	-20°F	-23°F	-25°F
Aged 168 hrs/275°F MIL-H-5606				
Shore A hardness	60 (-26)	50 (-12)	61 (-9)	32 (-32)
Tensile strength, psi	811 (-29%)	627 (-49%)	1089 (+18%)	475 (-60%)
Elongation	105%(-10%)	140%(-47%)	250%(-34%)	373%(-10%)
Tensile stress, 100%, psi	751 (-18%)	346 (-8%)	346 (+6%)	89 (-66%)
Volume change	+33.4%	+21.8%	+13.0%	+46.6%
Air-Aged 96 hrs/275°F				
Shore A hardness	82 (-4)	62 (0)	76 (+6)	67 (+3)
Tensile strength, psi	1195 (+4%)	1084 (-12%)	1224 (+33%)	1263 (+6%)
Elongation	97%(-21%)	197 (-28%)	220%(-42%)	363%(-12%)
Tensile stress, 100%, psi	--	463 (+23%)	629 (+92%)	365 (+37%)
Compression Set				
70 hrs/275°F	41%	53%	87%	82%

TABLE LIII - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS AND BLENDS

Ingredients	RAA-57	RAA-58	RAA-59	RAA-60	RAA-61
Thiacril 76	--	--	--	80.0	100.0
Chemigum AC	100.0	--	--	--	--
Hycar 2121X38	--	66.6	--	--	--
Thiacril 55	--	--	75.0	--	--
Cyanacril LT3	--	33.3	25.0	20.0	--
Stearic acid	1.0	1.0	1.0	0.8	1.0
Agerite Resin D	--	--	--	1.5	1.5
SAF Black	--	--	--	--	60.0
FEF Black	40.0	90.0	90.0	85.0	--
TP-95	--	--	10.0	20.0	25.0
TETA	--	1.5	--	--	--
MBTS	--	2.0	--	--	--
NA-22	2.0	--	2.5	--	--
Red Lead	5.0	--	5.5	--	--
Igepol CO-630	--	--	10.0	--	--
Diak No. 1	--	--	--	2.0	2.0
Ivory Beads	--	--	--	0.6	--
	148.0	194.4	219.0	209.9	189.5
Press cure	30 min/ 315°F	30 min/ 330°F	60 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	6 hrs/ 350°F	24 hrs/ 250°F	24 hrs/ 212°F	24 hrs/ 212°F	24 hrs/ 212°F

TABLE LIV - PROPERTIES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-57	RAA-58	RAA-59	RAA-60	RAA-61
Original Properties					
Shore A hardness	67	72	78	81	73
Tensile strength, psi	1763	398	858	1061	1389
Elongation	270%	133%	270%	110%	243%
Tensile stress, 100%, psi	484	336	462	1061	499
Temperature retraction	+15°F	-21°F	-24°F	-34°F	-35°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	52 (-15)	51 (-21)	65 (-13)	78 (-3)	77 (+4)
Tensile strength, psi	1156 (-34)	266 (-33%)	754 (-12%)	939 (-12%)	1467 (+6%)
Elongation	270%(0)	117%(-12%)	185%(-32%)	130%(+18%)	277%(+14%)
Tensile stress, 100%, psi	335 (-31%)	255 (-61%)	422 (-8%)	859 (-19%)	492 (-2%)
Volume change	+20.5%	+20.7%	+17.4%	+3.2%	+1.7%
Air-Aged 96 hrs/275°F					
Shore A hardness	68 (+1)	79 (+7)	82 (+4)	92 (+11)	81 (+8)
Tensile strength, psi	1722 (-2%)	517 (+30%)	1070 (+25%)	1090 (+3%)	1636 (+18%)
Elongation	250%(-7%)	113%(-15%)	170%(-37%)	77%(-30%)	247%(+2%)
Tensile stress, 100%, psi	560 (+17%)	517 (+54%)	962 (+108%)	--	584%(+17%)
Compression Set					
70 hrs/275° F	54%	76%	91%	71%	58%

TABLE LV - INGREDIENTS AND CURE SCHEDULES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-62	RAA-64	RAA-65	RAA-66	RAA-67
Thiacril 76	100.0	--	--	--	--
Hycar 2121X60	--	100.0	100.0	--	--
Hycar 4021	--	--	--	100.0	80.0
Cyanacril LT3	--	--	--	--	20.0
SAF Black	--	50.0	--	50.0	40.0
FEF Black	100.0	--	85.0	--	--
Stearic acid	1.0	1.0	1.0	1.0	1.0
TP-95	25.0	20.0	20.0	25.0	15.0
Dyphos	--	2.0	2.0	--	--
ESEN	--	1.5	1.5	--	--
Red lead	--	--	--	5.0	5.0
NA-22	--	--	--	2.0	2.0
Agerite Resin D	1.5	--	--	--	--
Diak No. 1	2.0	--	--	--	--
	229.5	174.5	209.5	183.0	163.0
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 400°F	30 min/ 400°F
Secondary oven cure	24 hrs/ 212°F	48 hrs/ 212°F	48 hrs/ 212°F	-- --	-- --

TABLE LVI - PROPERTIES OF POLYACRYLATE COMPOUNDS AND BLENDS

	RAA-62	RAA-64	RAA-65	RAA-66	RAA-67
Original Properties					
Shore A hardness	85	50	64	69	69
Tensile strength, psi	1178	845	774	1865	1364
Elongation	113%	410%	223%	340%	160%
Tensile stress, 100%, psi	1072	134	321	328	771
Temperature retraction	-26°F	-38°F	-49°F	-29°F	-20°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	85 (0)	38 (-12)	49 (-15)	66 (-3)	64 (-5)
Tensile strength, psi	1042 (-11%)	537 (-36%)	597 (-23%)	1320 (-29%)	854 (-37%)
Elongation	142%(+25%)	377%(-8%)	217%(-2%)	240%(-29%)	115%(-28%)
Tensile stress, 100%, psi	875 (-18%)	93 (-30%)	231 (-28%)	427 (+30%)	681 (-11%)
Volume change	+3.2%	+22.4%	+17.9%	+3.8%	+9.9%
Air-Aged 96 hrs/275°F					
Shore A hardness	91 (+6)	59 (+9)	70 (+6)	74 (+5)	76 (+7)
Tensile strength, psi	1053 (-11%)	984 (+16%)	902 (+17%)	1469 (-21%)	965 (-29%)
Elongation	97%(-12%)	423%(+3%)	220%(-1%)	243%(-28%)	105%(-34%)
Tensile stress, 100%, psi	--	198 (+47%)	417 (+30%)	546 (+66%)	923 (+19%)
Compression Set					
70 hrs/275°F	59%	42%	36%	61%	57%

TABLE LVII - INGREDIENTS AND CURE SCHEDULES OF BUTADIENE-ACRYLONITRILE COPOLYMERS

	RAN-31	RAN-32	RAN-33	RAN-34	RAN-35	RAN-36	RAN-37
Hycar 1001	75.0	75.0	85.0	--	--	--	--
Paracril 18-80	--	--	--	100.00	100.0	100.0	--
Butyl HT 1066	25.0	25.0	--	--	--	--	--
Hycar 1042	--	--	--	--	--	--	85.0
Phillips Cis 4-150	--	--	32.2	--	--	--	32.2
Hypalon 20	--	--	--	--	--	5.0	5.0
Tonic oxide	--	--	5.0	5.0	--	5.0	5.0
Zinc oxide	5.0	5.0	--	--	5.0	--	--
Stearic acid	1.0	1.0	1.0	1.0	15.0	1.0	1.0
FEF Black	45.0	45.0	34.0	65.0	65.0	65.0	--
SRF Black	30.00	30.0	34.0	--	--	--	75.0
SP 1055	--	12.0	12.0	12.0	12.0	12.0	12.0
Di Cup 40C	5.0	--	--	--	--	--	--
TP-95	--	15.0	15.0	15.0	--	15.0	15.0
	186.0	208.0	218.2	198.0	198.0	203.0	245.0
Press Cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary cure	16 hrs/ 250°F	16 hrs/ 250°F	6 hrs/ 212°F	--	6 hrs/ 212°F	--	--

TABLE LVIII - PROPERTIES OF BUTADIENE-ACRYLONITRILE COPOLYMERS

	RAN-31	RAN-32	RAN-33	RAN-34	RAN-35	RAN-36	RAN-37
Original Properties							
Shore A hardness	83	79	69	67	62	70	69
Tensile strength, psi	2335	2806	2045	2544	2499	2686	2275
Elongation	100%	150%	250%	260%	340%	240%	310%
Tensile stress, 100%, psi	2335	1757	588	538	357	632	613
Temperature retraction	+14°F	-4°F	-11°F	-47°F	-36°F	-44°F	-24°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	81 (-2)	83 (+4)	68 (-1)	63 (-4)	58 (-4)	72 (+2)	70 (+1)
Tensile strength, psi	781 (-66%)	1022 (-63%)	605 (-70%)	743 (-70%)	2499	847 (-68%)	671 (-70%)
Elongation	--	--	75%(-70%)	90%(-65%)	340%	80%(-66%)	70%(-77%)
Tensile stress, 100%, psi	--	--	--	--	357	--	--
Volume change	+36.5%	+30.3%	+23.4%	+23.5%	+27.3%	+25.2%	+10.2%
Air Aged 96 hrs/275°F							
Shore A hardness	90 (+7)	93 (+4)	89 (+20)	96 (+29)	95 (+33)	95 (+25)	92 (+22)
Tensile strength, psi	1547 (-33%)	1765 (-37%)	1779 (-13%)	--	*	--	1372 (-40%)
Elongation	40% (-60%)	40%(-73%)	40%(-84%)	Brittle	*	Brittle	30%(-90%)
Tensile stress, 100%, psi	--	--	--	--	*	--	--
Compression Set							
70 hrs/275°F	27%	57%	83%	77%	77%	72%	68%

* Test could not be made because properties of specimen were deficient.

TABLE LIX - INGREDIENTS AND CURE SCHEDULES OF BUTADIENE-ACRYLONITRILE COPOLYMERS AND BLENDS

	RAN-38	RAN-39	RAN-40	RAN-40A	RAN-41	RAN-42	RAN-43
Paracril 18-80	100.0	--	--	100.0	100.0	--	--
Ameripol CB	--	--	--	--	--	15.0	15.0
Hycar 1042	--	--	--	--	--	85.0	85.0
Hypalon 20	10.0	--	--	5.0	5.0	--	5.0
Phillips Cis 4-150	--	32.0	--	--	--	--	--
Hycar 1001	--	85.0	50.0	--	--	--	--
Dynagen XP 139	--	--	50.0	--	--	--	--
Carbon Wool 3Bl	--	--	--	35.0	35.0	40.0	--
FEF Black	65.0	--	--	35.0	35.0	--	--
MT Black	--	125.0	75.0	--	--	40.0	85.0
Zinc oxide	15.0	10.0	5.0	5.0	5.0	10.0	10.0
Stearic acid	1.0	1.0	1.5	1.0	1.0	0.5	1.0
SP 1045	--	--	--	12.0	--	--	12.0
SP 1055	12.0	--	--	--	12.0	--	--
TP-95	20.0	25.0	--	15.0	15.0	10.0	10.0
TMTD	--	--	--	--	--	2.5	--
ZNDMD	--	--	--	--	--	2.5	--
Litharge	--	--	--	--	--	2.5	--
Dioctyl Phthalate	--	8.5	5.0	--	--	--	--
Methyl Tuads	--	1.0	3.5	--	--	--	--
Agerite Resin D	--	2.0	--	--	--	--	--
NBC	--	--	5.0	--	--	--	--
Antioxident 2246	--	--	1.0	--	--	--	--
	223.0	239.5	196.0	208.0	208.0	208.0	223.0
Press cure	30 min/ 330°F	30 min/ 400°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 320°F	30 min/ 320°F
Secondary oven cure	--	--	--	--	--	--	--

TABLE LX - PROPERTIES OF BUTADIENE-ACRYLONITRILE COPOLYMERS AND BLENDS

	RAN-38	RAN-39	RAN-40	RAN-40A	RAN-41	RAN-42	RAN-43
Original Properties							
Shore A hardness	66	50	51	64	72	63	60
Tensile strength, psi	2290	388	477	1005	1176	573	1240
Elongation	250%	650%	460%	160%	120%	297%	760%
Tensile stress, 100%, psi	666	63	158	936	1126	489	143
Temperature retraction	-46°F	-17°F	-2°F	-45°F	-44°F	-26°F	-23°F
Aged 168 hrs/275°F MIL-H-5606							
Shore A hardness	73 (+7)	50	36 (-15)	67 (+3)	71 (-1)	33 (-30)	47 (-13)
Tensile strength, psi	819 (-64%)	184 (-52%)	263 (-44%)	764 (-24%)	890 (-24%)	208 (-64%)	424 (-66%)
Elongation	70%(-72%)	110%(-83%)	147%(-68%)	43%(-73%)	52%(-56%)	180%(-39%)	130%(-84%)
Tensile stress, 100%, psi	--	157%(+149%)	161 (+2%)	--	--	248 (-49%)	293 (+105%)
Volume change	+21.4%	+28.6%	+41.0%	+25.1%	+27.4%	+60.6%	+54.4%
Air-Aged 96 hrs/275°F							
Shore A hardness	98 (+32)	80 (+30)	70 (+19)	95 (+31)	95 (+23)	76 (+13)	90 (+30)
Tensile strength, psi	*	817 (+110%)	692 (+45%)	*	*	1189 (+108%)	*
Elongation	*	100%(-84%)	147%(-68%)	*	*	70%(-76%)	*
Tensile stress, 100%, psi	*	--	475 (+200%)	*	*	--	*
Compression Set							
70 hrs/275°F	70%	66%	68%	88%	75%	70%	90%

* Test could not be made because properties of specimen were deficient.

TABLE LXI - INGREDIENTS AND CURE SCHEDULES OF BUTADIENE-ACRYLONITRILE COMPOUNDS AND BLENDS

	RAN-45	RAN-46	RAN-47	RAN-50	RAN-51	RAN-52
Hycar 1001	85.0	85.0	50.0	--	--	--
Cis 4-150	32.2	32.2	--	--	--	--
Dynagen XP-139	--	--	50.0	--	--	--
Paracril 18-80	--	--	--	100.0	100.0	100.0
Hypalon 20	10.0	10.0	--	--	--	--
Zinc oxide	5.0	5.0	3.0	5.0	5.0	5.0
SP 1045	12.0	--	--	--	--	--
SP 1055	--	12.0	--	--	--	--
TP-95	20.0	20.0	--	15.0	15.0	15.0
FEF Black	35.0	35.0	--	--	--	--
SRF Black	35.0	35.0	45.0	--	--	--
MT Black	--	--	75.0	--	--	--
Stearic acid	--	--	1.0	1.0	1.0	1.0
Tetrone A	--	--	2.0	--	--	--
MBTS	--	--	0.5	--	--	--
Alon C	--	--	--	65.0	--	--
Di Cup 40C	--	--	--	6.0	--	--
NBC	--	--	1.0	--	--	--
Maglite Y	--	--	--	--	110.0	--
Maglite D	--	--	--	--	--	110.0
Agerite Resin D	--	--	--	--	2.0	2.0
TMTD	--	--	--	--	3.0	--
Sulfur	--	--	--	--	0.3	--
Varox	--	--	--	--	--	6.0
	234.2	234.2	227.0	192.0	236.3	239.0
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	6 hrs/ 212°F	6 hrs/ 212°F	--	--	--	--

TABLE LXII - PROPERTIES OF BUTADIENE-ACRYLONITRILE COMPOUNDS AND BLENDS

	RAN-45	RAN-46	RAN-47	RAN-50	RAN-51	RAN-52
Original Properties						
Shore A hardness	68	70	75	66	56	96
Tensile strength, psi	2103	2222	809	921	907	1109
Elongation	320%	260%	160%	360%	467%	40%
Tensile stress, 100%, psi	513	643	659	136	152	--
Temperature retraction	-18°F	-14°F	+3°F	-43°F	-57°F	--
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	70 (+2)	74 (+4)	55 (-20)	56 (-10)	40 (-16)	94 (-2)
Tensile strength, psi	892 (-58%)	992 (-55%)	266 (-67%)	591 (-36%)	409 (-55%)	*
Elongation	72% (-77%)	77% (-70%)	53% (-67%)	272% (-24%)	370% (-21%)	*
Tensile stress, 100%, psi	--	--	--	173% (+27%	83 (-45%)	*
Volume change	30.0%	+26.8%	+52.8%	+32.3%	+30.1%	+59.0%
Air-Aged 96 hrs/275°F						
Shore A hardness	89 (+21)	95 (+25)	95 (+20)	86 (+20)	73 (+17)	100+
Tensile strength, psi	2025 (-4%)	1879 (-15%)	861 (+6%)	1163 (+26%)	653 (-28%)	*
Elongation	42% (-87%)	37% (-86%)	27% (-83%)	240% (-33%)	243% (-48%)	*
Tensile stress, 100%, psi	--	--	--	680 (+400%)	437 (+182%)	*
Compression Set						
70 hrs/275°F	83%	76%	55%	100%	44%	64%

* Tests could not be made because properties of specimens were deficient.

TABLE LXIII - INGREDIENTS AND CURE SCHEDULES OF BUTADIENE - ACRYLONITRILE COMPOUNDS

	RAN-53	RAN-54	RAN-55	RAN-56	RAN-57	RAN-58
Paracril 18-80	100.0	100.0	100.0	100.0	100.0	100.0
Zinc oxide	5.0	5.0	5.0	5.0	5.0	5.0
FEF Black	65.0	65.0	60.0	--	--	--
Stearic acid	1.0	1.0	1.0	1.0	1.0	1.0
TP-95	15.0	15.0	15.0	15.0	15.0	15.0
Agerite Resin D	--	2.0	2.0	2.0	2.0	2.0
Varox	--	6.0	6.0	--	6.0	6.0
Maglite Y	--	--	--	150.00	--	75.0
Maglite D	--	--	--	--	75.0	--
TMTD	--	--	--	3.0	--	--
Sulfur	--	--	--	.3	--	--
Vulklor	4.0	--	--	--	--	--
	190.0	194.0	189.0	276.3	204.0	204.0
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--	--

TABLE LXIV - PROPERTIES OF BUTADIENE-ACRYLONITRILE COMPOUNDS

	RAN-53	RAN-54	RAN-55	RAN-56	RAN-57	RAN-58
Original Properties						
Shore A hardness	65	81	80	60	90	81
Tensile strength, psi	2402	1327	1915	1307	927	580
Elongation	283%	78%	100%	535%	65%	75%
Tensile stress, 100%, psi	456	--	--	149	--	--
Temperature retraction	-47°F	*	*	-52°F	*	*
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	80 (+15)	80 (-1)	76 (-4)	38 (-12)	90	80
Tensile strength, psi	808 (-66%)	808 (-39%)	591 (-69%)	542 (-59%)	912 (-16%)	603 (+4%)
Elongation	53% (-81%)	53% (-32%)	47% (-53%)	477% (-11%)	37% (-43%)	40% (-47%)
Tensile stress, 100%, psi	--	--	--	72 (-52%)	--	--
Volume change	+14.3%	+14.3%	+16.9%	+32.0%	+13.0%	+12.7%
Air-Aged 96 hrs/275°F						
Shore A hardness	98 (+33)	94(+13)	92 (+12)	78 (+18)	96 (+6)	90 (+9)
Tensile strength, psi	**	**	810 (-58%)	1121 (-14%)	1420 (+53%)	657 (+13%)
Elongation	**	**	0%	380% (-29%)	29% (-55%)	10% (-87%)
Tensile stress, 100%, psi	**	**	--	502 (+236%)	--	--
Compression Set						
70 hrs/275°F	72%	24%	26%	71%	47%	37%

** Tests could not be made because properties of specimens were deficient.
* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE LXV - INGREDIENTS AND CURE SCHEDULES OF BUTADIENE - ACRYLONITRILE COMPOUNDS

	RAN-59	RAN-60	RAN-61	RAN-62	RAN-63
Hycar 1014	100.0	--	--	--	--
Paracril 18-80	--	100.0	100.0	100.0	100.0
Zinc oxide	5.0	5.0	5.0	5.0	5.0
FEF Black	65.0	--	--	--	--
Maglite Y	--	150.0	150.0	175.0	200.0
TP-95	15.0	15.0	15.0	25.0	25.0
TMTD	--	--	--	3.0	3.0
Agerite Resin D	2.0	2.0	2.0	2.0	2.0
Varox	6.0	--	--	--	--
Stearic Acid	1.0	1.0	1.0	1.0	1.0
Methyl Tuads	--	3.0	3.0	--	--
Sulfur	--	0.3	0.3	0.3	0.3
Bismate	--	0.3	--	2.0	2.0
	194.0	276.6	276.3	313.3	338.3
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	24 hrs/ 212°F	--	--

TABLE LXVI - PROPERTIES OF BUTADIENE-ACRYLONITRILE COMPOUNDS

	RAN-59	RAN-60	RAN-61	RAN-62	RAN-63
Original Properties					
Shore A hardness	85	68	76	72	79
Tensile strength, psi	1313	1982	1139	1433	1468
Elongation	65%	460%	308%	407%	453%
Tensile stress, 100%, psi	--	252	322	349	464
Temperature retraction	*	-52°F	-46°F	-52°F	-43°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	82 (-3)	52 (-16)	47 (-26)	60 (-12)	60 (-19)
Tensile strength, psi	549 (-58%)	817 (-54%)	522 (-54%)	741 (-48%)	904 (-38%)
Elongation	32% (-54%)	343% (-25%)	313% (+2%)	370% (-9%)	350% (-22%)
Tensile stress, 100%, psi	--	234 (-7%)	145 (-55%)	254 (-27%)	297 (-36%)
Volume change	+18.1%	+26.1%	+32.4%	+22.0%	+22.3%
Air-Aged 96 hrs/275°F					
Shore A hardness	92 (+7)	81 (+13)	83 (+7)	88 (+16)	93 (+14)
Tensile strength, psi	1039 (-20%)	1867 (-6%)	1438 (+26%)	1500 (+5%)	1563 (+7%)
Elongation	20% (-69%)	393 (-15%)	297% (-4%)	300% (-26%)	250% (-45%)
Tensile stress, 100%, psi	--	694 (+175%)	648 (+101%)	799 (+129%)	104 (-77%)
Compression Set					
70 hrs/275°F	16%	55%	71%	73%	100%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE LXVII - INGREDIENTS AND CURE SCHEDULES OF BUTADIENE-ACRYLONITRILE COMPOUNDS

	RAN-64	RAN-65	RAN-66	RAN-67	RAN-70
Hycar 1024	--	--	100.0	--	--
Paracril 18-80	100.0	100.0	--	100.0	100.0
Zinc oxide	5.0	5.0	5.0	5.0	5.0
Stearic Acid	1.0	1.0	1.0	1.0	1.0
Maglite Y	150.0	175.0	175.0	150.0	150.0
FEF Black	25.0	--	--	--	--
TMTD	3.0	3.0	--	--	--
TP-95	25.0	12.5	12.5	--	--
Freon E3	--	12.5	12.5	--	--
Flexol GPE	--	--	--	15.0	--
Halby LTR 268	--	--	--	--	15.0
Methyl Tuads	--	--	3.0	3.0	3.0
Sulfur	0.3	0.3	0.3	0.3	0.3
Bismate	2.0	2.0	0.3	0.3	0.3
Agerite Resin D	2.0	2.0	2.0	2.0	2.0
	313.3	313.3	311.6	276.6	276.6
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--

TABLE LXVIII - PROPERTIES OF BUTADIENE-ACRYLONITRILE COMPOUNDS

	RAN-64	RAN-65	RAN-66	RAN-67	RAN-70
Original Properties					
Shore A hardness	68	76	80	63	77
Tensile strength, psi	1138	1473	1239	1346	749
Elongation	370%	348%	297%	580%	560%
Tensile stress, 100%, psi	239	364	346	161	200
Temperature retraction	-57°F	-40°F	-27°F	-46°F	-36°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	65 (-3)	62 (-14)	43	48	77
Tensile strength, psi	723 (-36%)	890 (-40%)	528 (-57%)	673 (-49%)	382 (-49%)
Elongation	210% (-43%)	323% (-7%)	230% (-22%)	395% (-31%)	390% (-30%)
Tensile stress, 100%, psi	352 (+47%)	254 (-30%)	185 (-46%)	160 (-6%)	143 (-28%)
Volume change	+19.7%	+27.4%	+49.0%	+25.4%	+31.2%
Air-Aged 96 hrs/275°F					
Shore A hardness	92 (+24)	91 (+15)	95	78	97
Tensile strength, psi	1250 (+9%)	1797 (+22%)	1474 (+19%)	1186 (-11%)	1172 (+56%)
Elongation	167% (-55%)	270% (-22%)	190% (-36%)	400% (-31%)	270% (-51%)
Tensile stress, 100%, psi	889 (+272%)	852 (+134%)	1073 (+210%)	513 (+218%)	767 (+283%)
Compression Set					
70 hrs/275°F	64%	79%	98%	76%	94%

TABLE LXIX - INGREDIENTS AND CURE SCHEDULES OF BUTADIENE ACRYLONITRILE COMPOUNDS

	RAN-68	RAN-69	RAN-71	RAN-72	RAN-73	RAN-74
Paracril 18-80	100.0	100.0	100.0	100.0	100.0	100.0
Zinc oxide	5.0	5.0	5.0	5.0	5.0	5.0
Stearic acid	1.0	1.0	1.0	1.0	1.0	1.0
Maglite Y	150.0	150.0	150.0	150.0	150.0	150.0
TMTD	3.0	3.0	3.0	3.0	3.0	3.0
Sulfur	.3	.3	.3	.3	.3	.3
Bismate	.3	.3	.3	.3	.3	.3
Agerite Resin D	2.0	2.0	2.0	2.0	2.0	2.0
Halby LTR-200	--	15.0	--	--	--	--
Thiokol TP 110	--	--	15.0	--	--	--
Plasticizer MT 511	--	--	--	15.0	--	--
Flexol EPO	15.0	--	--	--	--	--
Reichold DC-3089	--	--	--	--	15.0	--
Reichold DC-3090	--	--	--	--	--	15.0
	276.6	276.6	276.6	276.6	276.6	276.6
Press cure	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--	--

TABLE LXX - PROPERTIES OF BUTADIENE-ACRYLONITRILE COMPOUNDS

	RAN-68	RAN-69	RAN-71	RAN-72	RAN-73	RAN-74
Original Properties						
Shore A hardness	62	85	67	80	73	64
Tensile strength, psi	920	873	1329	1128	1212	891
Elongation	607%	313%	445%	313%	397%	707%
Tensile stress, 100%, psi	146	285	199	320	261	136
Temperature retraction	-36°F	-38°F	-42°F	-33°F	-34°F	-12°F
Aged 168 hrs/275°F MIL-H-5606						
Shore A hardness	32 (-40)	62 (-23)	57 (-10)	62 (-18)	51 (-22)	43 (-21)
Tensile strength, psi	396 (-57%)	554 (-36%)	1022 (-23%)	764 (-32%)	671 (-44%)	639 (-28%)
Elongation	380%(-37%)	240%(-23%)	317%(-29%)	273%(-13%)	317%(-20%)	440%(-80%)
Tensile stress, 100%, psi	66 (-54%)	252 (-11%)	235 (+18%)	279 (-13%)	204 (-22%)	123 (-10%)
Volume change	+33.5%	+29.4%	+26.8%	+29.9%	+20.7%	+22.6%
Air-Aged 96 hrs/275°F						
Shore A hardness	74 (+12)	98 (+13)	90 (+23)	91 (+11)	89 (+16)	83 (+19)
Tensile strength, psi	1153 (+25%)	1305 (+49%)	1643 (+23%)	1396 (+24%)	1302 (+7%)	1098 (+23%)
Elongation	527%(-13%)	200%(-36%)	275%(-38%)	253%(-19%)	130%(-67%)	160%(-78%)
Tensile stress, 100%, psi	410 (+180%)	889 (+212%)	827 (+316%)	838 (+162%)	1129 (+333%)	789 (+480%)
Compression Set						
70 hrs/275°F	88%	84%	75%	81%	69%	81%

TABLE LXXI - INGREDIENTS AND CURE SCHEDULES OF FLUOROSILICONE COMPOUNDS

	RAS-5	RAS-6	RAS-8	RAS-9
Silastic LS-X-30330U	--	--	--	100.0
Silastic LS63U	100.0	100.0	100.0	--
Cab-O-Sil MS-7	15.0	--	10.0	--
Luperco CSF	1.6	1.6	1.6	--
Carbon Wool 3B1	--	15.0	20.0	--
Varox	--	--	--	.5
	116.6	116.6	131.6	100.5
Press cure	5 min/ 240°F	5 min/ 240°F	5 min/ 240°F	10 min/ 340°F
Secondary oven cure	24 hrs/ 400°F	24 hrs/ 400°F	24 hrs/ 400°F	8 hrs/ 400°F

TABLE LXXII - PROPERTIES OF FLUOROSILICONE COMPOUNDS

	RAS-5	RAS-6	RAS-8	RAS-9
Original Properties				
Shore A hardness	87	77	91	78
Tensile strength, psi	924	740	576	876
Elongation	100%	160%	123%	95%
Tensile stress, 100%, psi	924	444	465	--
Temperature retraction	-83°F	-76°F	*	*
Aged 168 hrs/275°F MIL-H-5606				
Shore A hardness	85 (-2)	72 (-5)	84 (-7)	78 (0)
Tensile strength	803 (-13%)	689 (-7%)	544 (-6%)	705 (-19%)
Elongation	110%(+10%)	165%(+3%)	145%(+18%)	87%(-8%)
Tensile stress, 100%, psi	764 (-17%)	309 (-30%)	398 (-14%)	--
Volume change	+6.2%	+6.4%	+5.1%	+5.6%
Air-Aged 96 hrs/275°F				
Shore A hardness	88 (+1)	80 (+3)	90 (-1)	81 (+3)
Tensile strength, psi	972 (+5%)	732 (0)	559 (-3%)	742 (-15%)
Elongation	105%(-5%)	160%(0)	108%(-12%)	85%(-10%)
Tensile stress 100%, psi	898 (-3%)	464 (+5%)	523 (+12%)	--
Compression Set				
70 hrs/275°F	49%	29%	55%	14%

* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE LXXIII - INGREDIENTS AND CURE SCHEDULES OF PROPYLENE OXIDE RUBBER COMPOUNDS AND BLENDS

	RAQ-1	RAQ-2	RAQ-3	RAQ-4	RAQ-5
Dynagen XP139	100.0	100.0	100.0	60.0	100.0
Silastic LS63U	--	--	--	40.0	--
Carbon Wool 3B1	40.0	80.0	--	--	--
SRF Black	--	--	90.0	--	90.0
Cab-O-Sil MS7	--	--	--	25.0	--
Protox 166	3.0	--	--	--	--
Stearic acid	1.0	1.0	1.0	--	--
Zinc oxide	--	3.0	3.0	10.0	--
Sulfur	0.6	--	--	--	0.6
NBC	1.0	5.0	5.0	--	--
TP-95	--	5.0	15.0	--	--
TMTD	--	3.5	3.5	--	--
TMTM	1.0	--	--	--	--
Di Cup 40C	--	--	--	6.5	6.0
	146.6	197.5	217.5	141.5	196.6
Press cure	45 min/ 310°F	45 min/ 310°F	45 min/ 310°F	15 min/ 330°F	45 min/ 310°F
Secondary oven cure	--	--	--	4 hrs/ 300°F	--

TABLE LXXIV - PROPERTIES OF PROPYLENE OXIDE RUBBER COMPOUNDS AND BLENDS

	RAQ-1	RAQ-2	RAQ-3	RAQ-4	RAQ-5
Original Properties					
Shore A hardness	60	62	44	91	66
Tensile strength, psi	260	433	779	*	1177
Elongation	650%	100%	900%	*	210%
Tensile stress, 100%, psi	208	425	62	*	462
Temperature retraction	-88°F	-88°F	-88°F	*	-84°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	(too soft to test)	11 (-51)	3 (-41)	80 (-11)	*
Tensile strength, psi		34 (-92%)	49 (-93%)	*	*
Elongation		113% (+13%)	433% (-60%)	*	*
Tensile stress, 100%, psi		--	--	*	*
Volume change	(more than + 90%)	+210%	+283%	+15.8%	*
Air-Aged 96 hrs/275°F					
Shore A hardness	58 (-2)	59 (-3)	69 (+25)	*	*
Tensile strength, psi	327 (+26%)	331 (-24%)	732 (-6%)	*	*
Elongation	170% (-74%)	102% (+2%)	200% (-78%)	*	*
Tensile stress, 100%, psi	208 (0)	331 (+22%)	335 (+400%)	*	*
Compression Set					
70 hrs/275°F	54%	67%	94%	*	88%

* Tests could not be made because properties of specimen were deficient.

TABLE LXXV - INGREDIENTS AND CURE SCHEDULES OF PROPYLENE OXIDE RUBBER COMPOUNDS AND BLENDS

	RAQ-6	RAQ-7	RAQ-8	RAQ-9	RAQ-10
Dynagen XP-139	60.0	100.0	60.0	75.0	60.0
Hypalon 30	40.0	--	40.0	--	40.0
Hycar 1002	--	--	--	25.0	--
SRF Black	55.0	90.0	55.0	50.0	55.0
MT Black	35.0	--	35.0	--	35.0
Sulfur	--	--	--	--	--
Di Cup 40C	--	--	6.0	--	--
Zinc oxide	10.0	3.0	10.0	3.0	10.0
Stearic acid	1.0	1.0	1.0	1.0	1.0
Tetrone A	2.0	2.0	--	2.0	2.0
MBTS	0.5	0.5	--	.5	.5
NBC	1.0	1.0	--	1.0	1.0
TP-95	--	10.0	--	--	10.0
	204.5	207.5	207.0	157.5	214.5
Press cure	30 min/ 330°F	45 min/ 310°F	30 min/ 300°F	45 min/ 310°F	30 min/ 330°F
Secondary oven cure	4 hrs/ 300°F	--	4 hrs/ 250°F	--	--

TABLE LXXVI - PROPERTIES OF PROPYLENE OXIDE RUBBER COMPOUNDS AND BLENDS

	RAQ-6	RAQ-7	RAQ-8	RAQ-9	RAQ-10
Original Properties					
Shore A hardness	95	70	90	77	89
Tensile strength, psi	1773	1309	435	606	1104
Elongation	85%	317%	30%	123%	60%
Tensile stress, 100%, psi	--	427	--	579	--
Temperature retraction	*	-87°F	--	-37°F	*
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	96 (+1)	24 (-46)	99 (+9)	25 (-52)	85 (-4)
Tensile strength, psi	**	132 (-90%)	**	108 (-82%)	**
Elongation	**	253% (-20%)	**	37% (-70)	**
Tensile stress, 100%, psi	**	--	**	--	**
Volume change	+26.8%	+139.0%	**	+102%	**
Air-Aged 96 hrs/275°F					
Shore A hardness	100 (+5)	83 (+13)	100+	97 (+20)	100+
Tensile strength, psi	**	1052 (-19%)	**	**	**
Elongation	**	125% (-60%)	**	**	**
Tensile stress, 100%, psi	**	847 (+98%)	**	**	**
Compression Set					
70 hrs/275°F	99%	73%	99%	65%	99%

** Tests could not be made because properties of specimens were deficient.
* Test could not be completed - specimen failed at clamp when installed in apparatus.

TABLE LXXVII - INGREDIENTS AND CURE SCHEDULES OF POLYURETHANE COMPOUNDS AND BLENDS

	RAU-16	RAU-17	RAU-18	RAU-19	RAU-21
Elastothane 455	--	--	--	--	100.0
Genthane SR	100.0	100.0	--	--	--
Vibrathane 5004	--	--	--	100.0	--
Adiprene C	--	--	100.0	--	--
Hypalon 20	--	--	--	--	15.0
HAF Black	25.0	--	40.0	--	45.0
SRF Black	--	--	--	65.0	--
Carbon wool 3B1	--	20.0	--	--	--
SP 1045	--	--	--	--	--
Stearic acid	.3	--	--	--	1.0
SP 1055	--	--	--	--	12.0
Di Cup 40C	4.5	4.5	3.0	3.0	--
PCD	4.0	4.0	--	3.0	--
Butyl oleate	--	--	10.0	--	--
	133.8	128.5	153.0	170.0	173.0
Press cure	8 min/ 332°F	30 min/ 320°F	30 min/ 320°F	8 min/ 330°F	30 min/ 330°F
Secondary oven cure	2 hrs/ 300°F	2 hrs/ 300°F	4 hrs/ 212°F	4 hrs/ 212°F	--

TABLE LXXVIII - PROPERTIES OF POLYURETHANE COMPOUNDS AND BLENDS

	RAU-16	RAU-17	RAU-18	RAU-19	RAU-21
Original Properties					
Shore A hardness	56	57	60	84	70
Tensile strength, psi	3526	1139	3302	2020	1518
Elongation	650%	660%	470%	410%	230%
Tensile stress, 100%, psi	205	481	372	825	506
Temperature retraction	*	*	*	-21°F	-10°F
Aged 168 hrs/ 275°F MIL-H-5606					
Shore A hardness	44 (-12)	45 (-12)	30 (-60)	79 (-5)	52 (-18)
Tensile strength, psi	1857 (-47%)	757 (-33%)	1032 (68%)	2023	225 (-85%)
Elongation	660% (-1%)	775% (+17%)	450% (-0%)	250%	80% (-65%)
Tensile stress 100%, psi	241 (+17%)	235 (-51%)	66 (-82%)	821	--
Volume change	11.9%	+12.7%	+15.7%	+28.9%	+27.8%
Air-Aged 96 hrs/275°F					
Hardness	57 (+1)	50 (-7)	70 (+ 10)	88 (+ 4)	83 (+13)
Tensile strength, psi	2416 (-31%)	830 (-27%)	1959 (-40%)	2874 (+42%)	1129 (-26%)
Elongation	700% (+12%)	768% (+15%)	280% (-40%)	220% (-46%)	90% (-61%)
Tensile stress 100%, psi	173 (-15%)	308 (-36%)	384 (-3%)	1405 (+70%)	--
Compression Set					
70 hrs/275°F	82%	100% +	100% +	100%	99%

* Not conducted

TABLE LXXIX - INGREDIENTS AND CURE SCHEDULES OF POLYURETHANE COMPOUNDS AND BLENDS

	RAU-23	RAU-25	RAU-26	RAU-28
Elastothane 455	--	--	--	100.0
Genthane SR	100.0	100.0	70.0	--
Silastic 82 U	--	30.0	--	--
Silastic LS63U	--	--	30.0	--
Hypalon 20	--	--	--	15.0
HAF Black	60.0	60.0	--	45.0
SP 1[illegible]5	--	--	--	--
Stearic acid	.3	.3	.4	1.0
SP 1045	--	--	--	15.0
PCD	4.0	4.0	--	--
Di Cup 40C	8.0	10.0	--	--
5 Micron Min-U-Sil	--	--	50.0	--
Varox	--	--	6.0	--
	172.3	204.3	156.4	176.0
Press cure	30 min/ 330°F	30 min/ 330°F	25 min/ 320°F	30 min/ 330°F
Secondary oven cure	--	--	4 hrs/ 300°F	4 hrs/ 275°F

TABLE LXXX - PROPERTIES OF POLYURETHANE COMPOUNDS AND BLENDS

	RAU-23	RAU-25	RAU-26	RAU-28
Original Properties				
Shore A hardness	82	78	73	79
Tensile strength, psi	3654	2526	1011	2233
Elongation	320%	273%	283%	280%
Tensile stress, 100%, psi	695	447	650	756
Temperature retraction	-23°F	-28°F	-33°F	-7°F
Aged 168 hrs/275°F MIL-H-5606				
Shore A hardness	73 (-9)	56 (-22)	66 (-7)	53 (-26)
Tensile strength	1712 (-53%)	927% (-63%)	953 (-6%)	584 (-74%)
Elongation	270%(-15%)	302%(+10%)	290% (+3%)	147% (-47%)
Tensile stress, 100%, psi	417 (-40%)	211 (-53%)	431 (-33%)	335 (-55%)
Volume change	+5.1%	+24.2%	+4.4%	+21.9%
Air-Aged 96 hrs/275°F				
Shore A hardness	86 (+4)	87 (+9)	71 (-2)	89 (+10)
Tensile strength, psi	2493 (-32%)	1474 (-42%	1072 (+6%)	1630 (-27%)
Elongation	270 (-16%)	218% (-20%)	233% (-18%)	93% (-67%)
Tensile stress, 100%, psi	835 (+20%)	601 (+34%)	560 (-14%)	--
Compression Set				
70 hrs/275°F	93%	93%	95%	100%

TABLE LXXXI - INGREDIENTS AND CURE SCHEDULES OF CHLOROSULFONATED POLYETHYLENE COMPOUNDS AND BLENDS

	RAE-19	RAE-20	RAE-21	RAE-22	RAE-23
Dynagen XP-139	40.0	--	--	--	--
Hypalon 30	60.0	85.0	85.0	60.0	100.0
Nordel 1040	--	--	15.0	--	--
Genthane SR	--	--	--	40.0	--
Phillips Cis 4-150	--	32.2	--	--	--
Stearic acid	1.5	1.5	1.0	1.0	1.0
MT Black	50.0	75.0	75.0	45.0	85.0
FEF Black	--	--	20.0	--	--
HAF Black	--	--	--	20.0	--
Litharge	--	25.0	25.0	--	25.0
MBTS	0.5	0.5	0.5	--	0.5
NBC	1.0	--	--	--	--
Zinc oxide	10.0	--	--	--	--
Tetrone A	2.0	2.7	2.7	--	2.0
Maglite D	--	--	--	10.0	--
Agerite Resin D	--	--	--	2.0	--
Varox	--	--	--	6.0	--
TP-95	--	10.0	15.0	--	20.0
	165.0	231.9	239.2	184.0	233.5
Press cure	30 min/ 330°F	15 min/ 330°F	15 min/ 330°F	15 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--

TABLE LXXXII - PROPERTIES OF CHLOROSULFONATED POLYETHYLENE COMPOUNDS AND BLENDS

	RAE-19	RAE-20	RAE-21	RAE-22	RAE-23
Original Properties					
Shore A hardness	95	85	88	90	76
Tensile strength, psi	681	1818	1334	1291	1523
Elongation	10%	173%	140%	247%	195%
Tensile stress, 100%, psi	--	1009	1082	1105	653
Temperature retraction	--	+27°F	+15°F	+15°F	+10°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	100+	62 (-23)	60 (-28)	98 (+8)	72 (-4)
Tensile strength, psi	*	264 (-86%)	323 (-76%)	1283 (-6%)	468 (-69%)
Elongation	*	57%(-67%)	72%(-49%)	30%(-88%)	57%(-70%)
Tensile stress, 100%, psi	*	--	--	--	--
Volume change	+3.7%	+32.3%	+61.5%	+16.0%	+21.0%
Air-Aged 96 hrs/275°F					
Shore A hardness	*	94 (+9)	96 (+8)	96 (+6)	93 (+17)
Tensile strength, psi	*	1567 (-14%)	1741 (+30%)	1718 (+33%)	1458 (-4%)
Elongation	*	38%(-78%)	58%(-59%)	43%(-82%)	43%(-78%)
Tensile stress, 100%, psi	*	--	--	--	--
Compression Set					
70 hrs/275°F	*	89%	90%	100%	94%

* Test could not be made because properties of specimen were deficient.

TABLE LXXXIII - INGREDIENTS AND CURE SCHEDULES OF VINYL PYRIDINE COMPOUNDS AND BLENDS

	RAX-9	RAX-10	RAX-11	RAX-12	RAX-15
Philprene VP 15	100.0	--	--	--	--
Philprene VP 25	--	100.0	--	60.0	25.0
Philprene VPA	--	--	100.0	40.0	75.0
Zinc oxide	5.0	5.0	5.0	5.0	5.0
Stearic acid	1.0	1.0	1.0	1.0	1.0
FEF Black	65.0	65.0	65.0	65.0	60.0
Sulfur	--	--	0.25	--	--
Amberol ST 137X	--	--	--	12.0	--
TP-95	17.5	17.5	17.5	17.5	17.5
MBTS	3.0	3.0	3.0	--	--
TMTD	2.0	2.0	2.0	--	--
BLE antioxident	3.0	3.0	3.0	--	3.0
Benzotrichloride	20.0	20.0	20.0	20.0	20.0
Resin SP-1055	--	--	--	--	12.0
	216.5	216.5	216.75	220.5	218.5
Press cure	15 min/ 330°F	15 min/ 330°F	15 min/ 330°F	30 min/ 330°F	30 min/ 330°F
Secondary oven cure	--	--	--	--	--

TABLE LXXXIV - PROPERTIES OF VINYL PYRIDINE COMPOUNDS AND BLENDS

	RAX-9	RAX-10	RAX-11	RAX-12	RAX-15
Original Properties					
Shore A hardness	70	75	74	80	74
Tensile strength, psi	2374	2851	2687	2583	2094
Elongation	300%	300%	207%	155%	173%
Tensile stress, 100%, psi	426	647	866	1137	933
Temperature retraction	-28°F	-28°F	-16°F	-22°F	-23°F
Aged 168 hrs/275°F MIL-H-5606					
Shore A hardness	85 (+15)	81 (+6)	100 (+26)	94 (+14)	92 (+18)
Tensile strength, psi	*	351 (-87%)	1182 (-56)	*	*
Elongation	*	62%(-79%)	0	*	*
Tensile stress, 100%, psi	*	--	--	*	*
Volume change	+50.9%	+52.4%	+1.4%	+16.6%	+12.9%
Air-Aged 96 hrs/275°F					
Shore A hardness	96 (+26)	96 (+21)	99 (+25)	95 (+15)	96 (+24)
Tensile strength, psi	*	*	*	*	840 (-60%)
Elongation	*	*	*	*	10%(-94%)
Tensile stress, 100%, psi	*	*	*	*	--
Compression Set					
70 hrs/275°F	82%	75%	76%	62%	55%

* Test could not be made because properties of specimens were deficient.

TABLE LXXXV - INGREDIENTS AND CURE SCHEDULES OF MISCELLANEOUS COMPOUNDS

	RAX-5	RAX-6	RAX-7	RAX-14	RAC-53
Levaprene 450	--	--	--	100.0	--
Nitroso rubber	--	--	100.0	--	--
Fluororubber 2F4	--	100.0	--	--	--
Ultrathene UE 630X	100.0	--	--	--	--
Neoprene WRT	--	--	--	--	50.0
Neoprene ILA	--	--	--	--	50.0
Zinc oxide	--	--	--	--	5.0
Stearic acid	--	--	--	1.0	1.0
FEF Black	--	--	--	--	40.0
HMF Black	--	--	--	--	25.0
SRF Black	--	50.0	--	45.0	--
Sulfur	--	1.0	--	--	--
Maglite D	--	--	--	--	4.0
TP-95	--	--	--	--	15.0
TMTD	--	--	--	--	0.5
TETA	--	1.25	2.5	--	--
Antioxident PCD	--	--	--	1.0	--
Di Cup 40C	8.0	--	--	3.0	--
Activator OC	--	--	--	2.0	--
Quso H-40	--	--	15.0	--	--
Thiate E	--	--	--	--	0.5
Neozone D	--	--	--	--	2.0
	108.0	152.25	117.5	152.0	193.0
Press cure	8 min/ 330°F	30 min/ 310°F	60 min/ 185°F	35 min/ 310°F	15 min/ 330°F
Secondary oven cure	--	--	18 hrs/ 212°F	--	--

TABLE LXXXVI - PHYSICAL PROPERTIES OF MISCELLANEOUS COMPOUNDS

	RAX-5	RAX-6	RAX-7	RAX-14	RAC-53
Original Properties					
Shore A hardness	92	70	45	64	77
Tensile strength, psi	2019	972	227	2059	2590
Elongation	390%	273%	505%	248%	285%
Tensile stress, 100%, psi	593	283	76	327	780
Temperature retraction	-11°F	-29°F	-45°F	+13°F	-1°F
Aged 168 hrs/275° MIL-H-5606					
Shore A hardness	14 (-78)	72 (+2)	34 (-11)	33 (-31)	78 (+1)
Tensile strength, psi	*	953 (-2%)	49 (-79%)	130 (-94%)	1199 (-54%)
Elongation	*	260%(-3%)	410% (-19%)	83%(-51%)	93%(-67%)
Tensile stress, 100%, psi	*	317 (+12%)	49	--	--
Volume change	+244%	+4.0%	+0.2%	+164.0%	+29.1%
Air-Aged 96 hrs/275°F					
Shore A hardness	76 (-16)	79 (+9)	55 (+10)	66 (+2)	99 (+22)
Tensile strength, psi	*	855 (-12%)	68 (-70%)	1941 (-6%)	*
Elongation	*	220%(-19%)	230%(-54%)	320%(+22%)	*
Tensile stress, 100%, psi	*	349 (+23%)	85 (+12%)	285 (-13%)	*
Compression Set					
70 hrs/275°F	*	81%	--	19%	81%

* Tests could not be made because properties of specimens were deficient.

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DEVELOPMENT OF A LONG LIFE O-RING COMPOUND FOR USE IN AIRCRAFT HYDRAULIC SYSTEMS USING MIL-H-5606 FLUIDS AT PRESSURES UP TO 3000 PSI AND TEMPERATURES RANGING FROM -65°F to +275°F

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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5. AUTHOR(S) (Last name, first name, initial)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Materials Engineering Branch, Materials Applications Div. Air Force Materials Laboratory, Research and Technology Div. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

This Summary Technical Report describes the program for the development of a long life O-ring compound for use in aircraft hydraulic systems using MIL-H-5606 fluids at pressures up to 3000 psi and temperatures ranging from -65°F to +275°F. Compounding and blending efforts conducted during the program explored fluoroelastomers, polyacrylates, butadiene-acrylonitrile copolymers, epichlorohydrin elastomers, propylene-oxide rubber, polyurethane elastomers, chlorosulfonated polyethylenes, silicones, and others. Static and dynamic O-ring evaluations conducted on MIL-P-25732 buna N compounds confirmed contentions that this compound has limited heat resistance at 275°F, especially when it experiences some exposure to air. The same tests conducted on MIL-R-25897 fluoroelastomer compounds have shown that they have poor compression set characteristics, low temperature limitations, and poor extrusion resistance. Two compounds developed during the program exhibited performance superior to the aforementioned Military Specification compounds when evaluated in static and dynamic O-ring tests. The first of these compounds utilized Hydrin 200, a copolymer of epichlorohydrin with ethylene oxide produced by the B. F Goodrich Company; the other was an ECD-487 (E. I. DuPont de Nemours low temperature Viton) compound. Performance evaluations of the epichlorohydrin O-rings indicated that an increase in service life of 50 to 100% can be expected over buna N compounds under static and dynamic conditions when completely immersed in hydraulic fluid. In addition, 100 to 200% increase in service life can be expected when the seals are partially exposed to air. There is no increase in life for the ECD-487 over buna N when completely immersed in hydraulic fluid, but there is an increase of 150 to 300% when partially exposed to air. Of the two, the Hydrin formulation is preferred since it survived the most hours of O-ring testing in three of the four tests conducted. In addition, it may be easily processed and is moderately priced. It is anticipated that this copolymer will be available in production quantities in the future.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
O-Rings Type II Hydraulic Systems Elastomers Elastomeric Compounds Hydraulic Seals Hydraulic Packings Fluoroelastomers Epichlorohydrin Polymers MIL-P-25732 MIL-R-25897						

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INFORMATION

AD-485022

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REPUBLIC AVIATION DIVISION

To: Recipients of final report of Contract AF33(615)-1668:

Development of a Long Life O-ring Compound for Use in Aircraft Hydraulic Systems Using MIL-H-5606 Fluids at Pressures up to 3000 psi and Temperatures Ranging from -65°F to +275°F.

Subject: Errata Sheet for AFML-TR-66-73

Gentlemen:

Copies of the subject report in your possession should be revised as follows:

Page 84 (TABLE XXVII) is presently shown as:

	RAK-3	RAK-4
Diak No. 1	1.6	1.6
NA-22	--	--

These lines should be changed to:

Diak No. 1	--	--
NA-22	1.6	1.6

It is suggested that this memo be attached to the report. Sufficient copies are enclosed to cover all copies sent to you.

Very truly yours,

FAIRCHILD HILLER
Republic Aviation Division

R. Schroeder

RS:mb

R. Schroeder