CEMILAC/4104/LIB/REP/38/2009-2010
November 2009

ELASTOMERS IN AERONAUTICS
(A COMPENDIUM)

REGIONAL CENTRE FOR MILITARY AIRWORTHINESS
(Foundry & Forge – Fuels, Oils, Lubricants)
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION
DRDO, Ministry of Defence, Govt. of India, Marathahalli, Bangalore-560037

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FOREWORD

Any engineering equipment or system is an assembly of a variety of components made from different types of materials. Selection of materials is largely dictated by functional/performance requirements and the environment which determines protective treatment needs and eventually the life. Among these different kinds of materials, rubbers/elastomers assume significance from their uniqueness in engineering properties and adaptability in building equipment. Elastomers have the ability to substantially deform under the application of load and regain its original shape and size upon withdrawal of load. Similar to metallic materials, Elastomers can be tailored to prepare components but the distinction is that Elastomers are known to have limited shelf life and often need replacement due to sensitivity to small defects like nicks, cuts, surface decay and such other observations. The Indian Military Aviation has wide variety of aircraft imported or built to specifications of those countries of origin. This kind of inventory of aircraft has given challenge to indigenization. The innovative efforts have brought in a number of types of Elastomers besides natural rubber to perform in a variety of environments like oil, fuel and ambient atmosphere with fluctuations in temperature and humidity. The role of the elastomeric components is at times critical and non availability of a particular type may lead to Aircraft on Ground (AOG) situation.

Indigenization efforts have brought in numerous industries to produce aeronautical grade Elastomers and their components and today the industries are [illegible] and are embarking on export potential.

The present scenario of self reliance achieved in Elastomers and their components as seals, gaskets, [illegible], mounts etc., as evidenced through type approvals accorded by CEMILAC reveals that a compendium can serve as a reference document to the designer, user services, practicing engineers and technologists. Towards this goal, the present compendium containing requisite details of chemistry, properties, relevant specifications, application areas, Airworthiness approval references and sources of the elastomeric components is a useful compilation. I am sure it will serve as a reference document to the aeronautical community in particular and engineers in general.

I congratulate the team of officers and staff led by Dr.P.Raghothama Rao, Sc 'G', Regional Director of RCMA (F&F-[illegible]) along with HAL (F&F) for their strenuous efforts in bringing out this compendium.

Place: Bangalore-560 037
Date: 25 November 2009

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Scientist 'H' & Outstanding Scientist
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ABSTRACT: Rubber is the most fascinating material known to mankind both on account of its range of applications in everyday life, defence and civilian purposes and its behaviour under the most diverse conditions of application. This compendium is a compilation of the variety of Elastomers used in the aviation industry. The types include Natural, Nitrile, Neoprene, Butyl, Silicone, Fluorocarbon, Ethylene Propylene rubber and Hypalon. The properties and applications are highlighted for each of the Elastomers in this compendium. Elastomers play major role in sealing technology. Seals are a few of the most important engineering components in use today. It is functional in preventing viscous, corrosive, inflammable fluids from leakage under high pressure or temperature in static or dynamic condition. Seal selection depends on factors like physical, chemical, thermal, pressure/vacuum, contamination and economy. This report defines the key terms and details the procedure in rubber compounding, ingredients, additives and testing of Elastomers. Last but not the least, this report includes the airworthiness certification procedure for type approval of compound and components, list of indigenized rubber compound and components for various projects like Adour, Dart, Jaguar, HPT-32, Cheetah/Chetak, LCA, LCH and ALH.

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1 INTRODUCTION

ASTM D 1566 defines rubber as a material that is capable of recovering from large deformations quickly and forcibly in its modified state, free of diluents, retracts within one minute to less than 1.5 times its original length and held for one minute before release. The same standard, on the other hand, defines an Elastomer as a macromolecular material which, at room temperature, is capable of recovering substantially in shape and size after removal of a deforming force. Thus, by these definitions, it can be stated that all rubbers are Elastomers, but all the Elastomers are not rubbers. In the definition of Elastomers, neither return time nor deformation hold time is specified.

Rubbers are a class of materials that serves to an enormous number of engineering needs in the fields dealing with shock, noise and vibration control, sealing, corrosion protection, abrasion protection, friction protection, electrical and thermal insulation, provide water proofing and load bearing. Generally, raw rubber tends to be soft and sticky in hot condition, hard and brittle in cold condition. In order to make these rubbers/Elastomers suitable for service applications as well as enhancing their performance, additives/suitable ingredients are added to them. This process is termed as compounding of rubbers/Elastomers. Similarly, for further improvement in the performance of the rubbers/Elastomers, vulcanisation process is carried out at higher temperatures. This process involves cross-linking of the polymer chain with their corresponding cross-linking agents. This vulcanisation operation extends the temperature range within which they are flexible and elastic. In addition to vulcanising agents, ingredients are added to make Elastomers stronger, tougher, or harder, to make them age better, to color them and in general to impart specific properties to meet specific applications.

Elastomers are primarily composed of large molecules that tend to form spiral threads, similar to a coiled spring, that are attached to each other at infrequent intervals. These coils tend to stretch or compress on the application of the stress and exhibit an increasing resistance to the subsequent application of stresses.

Rubber is water repellent and resistant to alkalies and weak acids. Some of the special features of rubbers, such as elasticity, toughness, impermeability, adhesiveness and electrical resistance make them useful as an adhesive, a coating composition, a molding compound and an electrical insulator. In general, synthetic rubber has the following advantages over natural rubber: as this possesses improved resistance to aging and weathering, oil, solvents, oxygen, ozone and certain chemicals over a wide temperature range. On the other hand, the advantages of natural rubber are comparatively lesser buildup of heat during flexing and greater resistance to tearing when hot.

2 OBJECTIVE OF STUDY

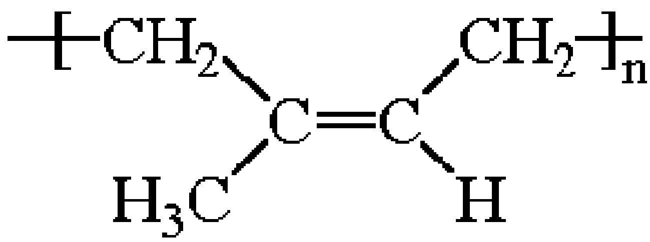
Elastomers play major role in the aviation industry. At present more than 1500 rubber/Elastomer components conforming to more than one hundred different material specifications, viz, Natural, Nitrile ,Butyl, Neoprene, SBR, Hypalon, Fluorosilicone, Fluorocarbon have been indigenized and being used successfully in aviation industry. Therefore, it was felt necessary to compile structure, properties and applications of various Elastomers and rubber compounds and components with their shelf life and their corresponding airworthiness certification which is being carried out by the Center for Military Airworthiness and Certification (CEMILAC), Bangalore, an Airworthiness Approval Authority (AAA) for military aircraft in India.

3 TYPES OF ELASTOMERS USED IN AIRCRAFT

3.1 Natural Rubber (NR)

3.1.1 Structure

Natural rubber is an Elastomer (an elastic hydrocarbon polymer) that was originally derived from a milky colloidal suspension, or *latex*, found in the sap of rubber tree. The purified form of natural rubber is the chemical polyisoprene (as shown below), which can also be produced synthetically. Natural rubber is used extensively in many applications and products as is synthetic rubber.



3.1.2 Properties

The properties of natural rubber are as follows:

- Natural rubber has a large deformability capacity. This, coupled with its ability to strain crystallize, gives it an added strength when it deforms.
- Its high resilience, which is the cause of its very low heat buildup during flexing, makes NR a prime candidate for shock and severe dynamic loads
- NR also has low compression set and stress relaxation; these characteristics favor its application in sealing devices where maintenance of sealing forces and the surface conformability of high-quality soft stocks are important
- It also possesses excellent green strength as well as adequate abrasion resistance
- The useful service temperature of NR ranges generally from -54°C to +120°C
- Shortcomings of NR such as poor oil, oxidation and ozone resistance can be minimized by compounding.

3.1.3 Grades

Various grades of natural rubber are shown in Table 1.

Table 1 Grades of Natural Rubber

Section in Green book*	Type	Grade

1	Ribbed smoked sheets	1X RSS, RSS Nos. 1-5
2	Thick Pale Crepes Thin Pale Crepes	1X 1,2,3 1X 1,2,3
3	Estate brown thick Crepes Estate brown thin Crepes	1X,2X,3X 1X,2X,3X
4	Compo Crepes	1,2,3
5	Thin brown Crepes (remills)	1,2,3,4
6	Thick blanket Crepes (Ambers)	2,3,4
7	Flat bark Crepe	Standard, hard
8	Pure smoked blanket Crepe	Standard

*International Standards of Quality and Packing for Natural Rubber Grades

Ribbed smoked sheets are marketed based on visual assessment of quality. For commercial purposes the grade description of Natural Rubber (in accordance with Green Book) given in the Table 1, are as per the international Rubber Quality and Packing conference.

3.1.4 Technical Grades of Natural Rubber

Dry natural rubbers graded on the basis of technical parameters are called Technically Specified Rubbers and are listed in Table 2**.**

Table 2 Technical Grades of Natural Rubber

Property	SMR L, CV	SMR 5	SMR 10	SMR 20	SMR 50
Dirt content, %	0.03	0.05	0.10	0.10	0.50
Ash content, %	0.50	0.60	0.75	0.75	1.50
Nitrogen content, %	0.60	0.60	0.60	0.60	0.60
Volatile matter, %	0.80	0.80	0.80	0.80	0.80
Wallace plasticity	30.00[1]	30.00	30.00	30.00	30.00
PRI, %	60.00	60.00	60.00	40.00	30.00

1 Does not apply to SMR CV.

SMR L: This is a very clean, light colored rubber.

SMR CV: This refers to a constant viscosity (CV) rubber. It is produced by adding hydroxylamine neutral sulfate before coagulation. It comes in several viscosity grades. The CV rubbers have fewer Mooney viscosity variations between lots and change less with age.

SMR 5: SMR 5 and SMR 1 are produced from factory-coagulated latex but do not go through the Ribbed Smoked Sheet (RSS) process. This is a very clean grade of rubber but is darker than SMR L

SMR 10, 20 and 50: These grades are produced from field coagulation but may contain some RSS.

There are several other forms and grades of natural rubber, such as oil extended Natural Rubber, which is made by adding either aromatic or naphthenic oil to the latex before coagulation, or by blending in an extruder with the dry rubber. One of the newer and more interesting variations of natural rubber is epoxidized natural rubber, called Epoxyprene. Epoxyprene comes in two grades, ENR-20 and ENR-50. The double bonds in the backbone are epoxidized to 20 mole% and 50 mole%, respectively, to make these grades. Epoxidation changes several physical properties, including increasing the glass transition temperature (T_g) of the polymer. These polymers have higher damping capacity, lower permeability to gases and increased polarity which reduces swelling in non polar oils. Increased damping properties of Epoxyprene can be utilized in the acoustic devices; increased T_g can be utilized to improve wet traction in tire treads.

3.1.5 Aeronautical Applications

Table 3 illustrates the Aeronautical Applications of Natural Rubber.

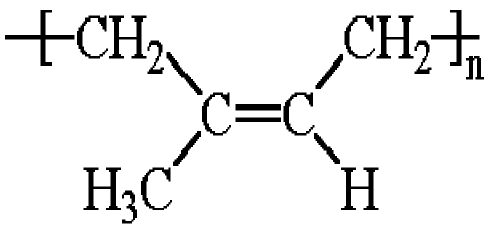
Table 3 Aeronautical Applications of Natural Rubber

Project	Part No.	Part Name	Material Spec.
ALH	201X 672H 3150 213/H, 201X 672H 3150 214/H	Spacer-Rubbers	HM 4931/ 1157
Kiran MKI/MKIA	APRL-M-039	Inner tube for nose wheel	Halnat 02 / HM 4932 issue A

3.2 Isoprene Rubber (IR):

3.2.1 Structure

Synthetic polyisoprene is designed to be similar to natural rubber in structure and properties. This can be shown by means of the following molecular structure:



Although, it still demonstrates lower green strength, slower cure rates, lower hot tear and lower aged properties than its natural counterpart, synthetic polyisoprene exceeds the natural types in consistency of product cure rate, processing and purity. In addition, it is superior in mixing, extrusion, molding and calendaring processes.

3.2.2 Properties

The physical properties of IR are in general somewhat inferior to those of natural rubber but, in principle, the two types of rubber are quite similar. Properties of IR are as follows:

- This rubber has almost the same chemical structure as natural rubber (polyisoprene).
- It does not contain proteins, fatty acids and the other substances as impurities that are present in natural rubber.

- This rubber demonstrates lower green strength, slower cure rates, lower hot tear and lower aged properties than natural rubber.
- IR exhibits superior consistency of product, cure rate, purity and processing than the natural rubber.
- In addition, this rubber has the unique property in mixing, extrusion, molding and calendaring processes.

3.2.3 Grades

Various grades of the rubber are tabulated in Table 4.

Table 4 Grades of Isoprene Rubber

Property	**NIPOL IR 2200**	**NIPOL IR 2200L**	**NIPOL IR 2200N**	**NATSYN 2200**	**NATSYN 2205**	**NATSYN 2210**
CAS	9003-31-0	9003-31-0	9003-31-0	9003-31-0	9003-31-0	9003-31-0
Mooney ML_4 @ 100°C	75-90	65-80	75-90	70-90	70-90	50-70
Heat loss, % max.	0.7	1.0	1.0	Not reported	Not reported	Not reported
Volatile matter, %	-	-	-	0.5	0.5	0.5
Ash, % max.	0.5	0.5	0.5	0.5	0.6	0.6
Extractables, %	Not reported	Not reported	Not reported	<3.0	<3.0	<3.0
$T_{g,}$ °C	-75	-75	-75	Not reported	Not reported	Not reported
Cis-1,4 content, %	98.0	98.0	98.0	~99.0	~99.0	98.5
Specific Gravity	0.91	0.91	0.91	0.91	0.91	0.91
FDA Compliant*	Yes	Yes	Yes	Yes	Yes	Yes
Package size, kg	35.0	35.0	17.5	34.0	34.0	34.0
Package size, lb	77.1	77.1	38.6	75.0	75.0	75.0
Shelf life	3 years	3 years	3 years	18 months	18 months	18 months

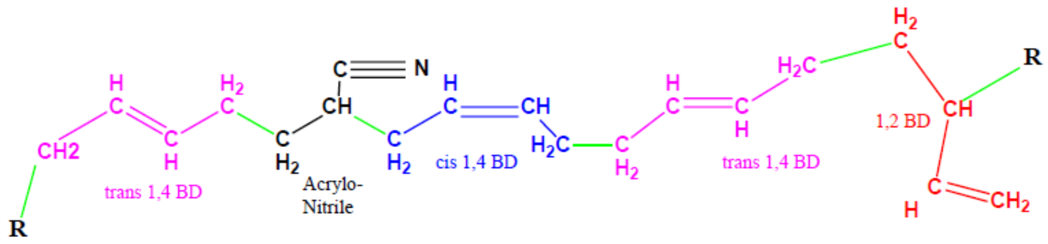
3.2.4 Aeronautical Application

Isoprene rubber is generally used in aircraft tires.

3.3 Nitrile Rubber (NBR)

3.3.1 Structure

Nitrile Rubber is a synthetic rubber produced by polymerization of acrylonitrile with butadiene. This rubber is also known as acrylonitrile-butadiene rubber (NBR), acrylonitrile rubber or Nitrile-butadiene rubber. The molecular structure is as shown below.



This type of synthetic rubber is widely used in number of applications. Nitrile Rubber belongs to the family of unsaturated copolymers of acrylonitrile (ACN) and butadiene. The physical and chemical properties of this rubber vary depending on the polymer's composition of acrylonitrile. Different grades are available for this rubber. Normal NBR is the most common form of NBR and is widely used. Depending upon acrylonitrile content and Mooney viscosity, normal NBR may be further divided into three types i.e. Low Nitrile (18-24 % ACN content), Medium Nitrile (25-30% ACN content) and High Nitrile NBR (30-40% ACN content).

3.3.1 Properties

The properties of NBR are shown below

- The higher the acrylonitrile content within the polymer, the higher the oil resistance
- It is generally resistant to fuel and other chemicals
- It can withstand a range of temperatures **(–40°C to +125°C)**
- It has inferior strength and flexibility, compared to natural rubber
- This rubber is also resistant to aliphatic hydrocarbons
- It is less resistant to ozone, aromatic hydrocarbons, ketones, esters and aldehydes
- It has high resilience and high wear resistance but only moderate strength
- It has limited weathering resistance
- It can generally be used down to about -30º C, but special grades can also operate at much lower temperatures

3.3.2 Grade

Various grades of the rubber are exhibited in Table 5.

Table 5 Grades of Nitrile Rubber

Country	**Producer**	**Trade name**	**Range of acrylonitrile content**	**Special grades**
UK	BP chemical	Breon	28-41	NBR 232: liquid polymer
	Revertex	Butakon A	27-40	XNR 233:high gel, process aid
France	Compagnie Francaise Goodyear	Chemigum	30-48	N8: cross linked process aid

	Plastugil	Butacril	20-40	Cross linked process aid
	Polymer Corpn.	Polysar Krynac	27-50	833: isoprene acrylonitrile
Italy	ANIC	Europrene N	20-40	Cross linked process aid
	Montecatini	Elaprim	21-45	-
Netherlands	Chemische Industrie AKU-Goodrich	Hycar	ML – H^{+}	-
W. Germany	Bayer	PerbunanN	28-39	NS: antioxidant approved for food stuffs

$^{+}$ ML-H = medium low to high

3.3.3 Aeronautical Application

The Aeronautical Applications of Nitrile rubbers are given in Table 6.

Table 6 Aeronautical applications of Nitrile Rubber

Project	Part No.	Part Name	Material Spec.
Dart	30781118478/H	RING SEALING	DTD 5509 GR. B
Ch/Ck	AN 931-16-22/H	GROMMET	BACM 573D GR 45
Ch/Ck	3130-23-20-008/H	GROMMET	BACM 573D GR 45
Jaguar	CSP 4CD-021/H	`O' RING	DTD 560 Gr 'C' Q/P
Jaguar	CSP 4CD-327/H	`O' RING	DTD 560 Gr 'C' Q/P
Jaguar	M 20467-4/H	`O' RING	DTD 560 Gr 'C' Q/P
Jaguar	M 20956/H	`O' RING	DTD 5509 GR. B
Jaguar	324-58206/H	RUBBER SEAL	DTD 560 Gr 'C' Q/P
Kiran	150-29114 A	TAIL SKID BUMPER	DTD 560 Gr 'C' Q/P
Kiran	324-58211	RUBBER SEAL	DTD 560 Gr 'C' Q/P
Kiran	324-59207	RUBBER SEAL	DTD 560 Gr 'C' Q/P
Kiran	GD 1480/2C (M20472-2)	STRUD	DTD 560 Gr 'C' Q/P
Kiran	SP 900-7	`O'RING	DTD 560 Gr 'C' Q/P
Kiran	11138Y2	SEAL	21B8
HS 748	HS 748-4284	RUBBER SEAL	DTD 458A GR.B1
HS 748	HS 748-4329	RING SEAL	21B8
HS 748	HS 748-4603	RUBBER SEAL	DTD 458A GR.B1
HS 748	HS 748-4605	RUBBER SEAL	DTD 458A GR.B1
HS 748	HS 748-4695	RUBBER SEAL	DTD 458A GR.B1
HS 748	HS 748-4736	`O'RING	DTD 458A GR.B1
HS 748	HS 748-4739	RUBBER SEAL	DTD 458A GR.B1
HS 748	HS 748-4747	RING SEAL	DTD 458A GR.B1
HS 748	HS 748-4753	RING SEAL	DTD 458A GR.B1
HS 748	HS 748-4765	RING SEAL	DTD 458A GR.B1

3.4 Polychloroprene / Neoprene (CR)

3.4.1 Structure

Neoprene is a type of synthetic rubber that is produced by polymerization of chloroprene. The molecular structure is represented as below and polymer chips are shown in Figure 1.

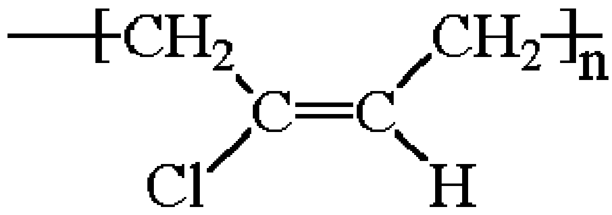


Figure 1 Polychloroprene

The modern chloroprene process, which is now used by nearly all producers, is based on butadiene, which is readily available. Butadiene is converted into the monomer 2-chlorobutadiene-1, 3 (chloroprene) via 3, 4- dichlorobutene-1. In principle it is possible to polymerize chloroprene by anionic, cationic and Ziegler-Natta catalysis techniques.

3.4.2 Properties

The properties of polychloroprene are described as below:

- Tensile Strength slightly lower than natural rubber but better than Nitrile rubber
- High tear strength can be obtained by using a lower degree of cure
- A good resistance to compression set
- It is flame resistant and considerably resistant to many chemicals
- It has excellent resistance to weather and ozone
- This rubber is suitable for use with mineral oils, greases, dilute acids and alkalis
- It is less resistant than natural rubber to low temperature stiffening
- Moderate oil and fuel resistance

3.4.3 Grade

Various grades of the rubber are illustrated in Table 7.

Table 7 Grades of poly chloroprene

Producer	Trade name	Modifier	Mooney viscosity*	Crystallization rate +
Du Pont (UK)	Neoprene	Sulphur	M	M.L
		Non – sulphur	L	H
		Non – sulphur	M	H, M, VL
		Non – sulphur	H	H, VL
Bayer (Germany)	Baypren	Sulphur	M	M,L
		Mercaptan	L	H
		Mercaptan	M	H, VL
		Mercaptan	H	M, VL
Distugil (France)	Butaclor	Sulphur	M	M,L
		Mercaptan	L	H
		Mercaptan	M	H,M, VL
		Mercaptan	H	M,VL

*L=low (40 and below); M=medium (around 50); H=high (around 100);

+VL-very low; L-low; M- medium; H-high.

3.4.4 Aeronautical Applications

Table 8 shown below illustrates the Aeronautical Applications of polychloroprene rubber.

Table 8 Aeronautical Applications of Polychloroprene Rubber

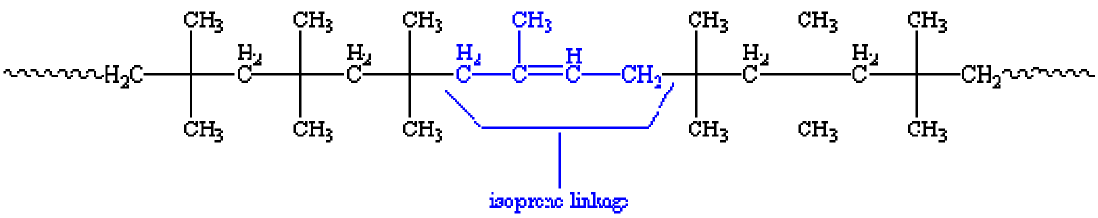
Project	Part No.	Part Name	Material Spec.
ALH	2-73017/H	CAP	31B5
ALH	201P 252H 4100 205/H	RUBBER PAD (TOP)	31B6
ALH	201P 521H 3201 001/H	RUBBER SPIGOT FITTING ASSEMBLY	31B5
ALH	201P 656H 3000 203/H	ELASTOMERIC BUSH	31B6
Ch/Ck	SE 3160S.25.22.068/H	STOP RUBBER	31B5
Ch/Ck	2-73017/H	CAP	31B5
Ch/Ck	315A-21-28-020/H	RING ASSY. SHOCK ABSORBER	31B6
Ch/Ck	3130-46-10-007/H	MOLDED STRIP	31B8
Ch/Ck	3160-21-15-011/H	STOP RUBBER FLOOR HATCH	31B6
Ch/Ck	3160S-35-30-516/H	SEAL,RUBBER	31B8
Jaguar	FA 1947-2/H (M 21344)	CAP	31B5
Jaguar	SR 137/H (M 20882)	`O' RING	31B6
Jaguar	121E-23-130-230/H	TAMPON STOPPER	31B8

Jaguar	121E-63-230-030/H	RUBBER SEAL	31B5
Jaguar	121E-77-325-400/H	SHOCK MOUNT	31B4
Kiran	M 20839 (FA 1947-3)	RUBBER BUSH	31B5
Kiran	SP 95/A20	GROMMET	DTD 5514 Gr 'D'
HS 748	HS 748-3057	RUBBER CLEAT	31B8
HS 748	HS 748-4609	RUBBER SEAL	31B8
HS 748	HS 748-4752	WASHER SEAL	31B8
HS 748	HS 748-4768	`O' RING	31B8
HS 748	HS 748-4775	RING SEAL	31B8
HS 748	HS 748-4788	GROMMET	31B8
HS 748	HS 748-4791	GASKET	31B8
HS 748	HS 748-4796	GASKET	31B6
HPT 32	HPT 32 -5059	WASHER	31B8

3.5 Butyl Rubber (IIR)

3.5.1 Structure

Butyl rubber—also known as polyisobutylene, PIB $(C_4H_8)_n$ is a synthetic rubber and a homopolymer of 2-methyl-1-propene and the molecular structure is as shown below.



Polyisobutylene is produced by polymerization of about 98% of isobutylene with about 2% of isoprene. Structurally, polyisobutylene resembles polypropylene, having two methyl groups substituted on every other carbon atom.

3.5.1 Properties

The properties of butyl rubber are described below:

- This rubber consists of isobutene with a minor part of isoprene
- The isoprene helps the rubber to unsaturate and possible to vulcanize
- Generally for all rubber types, the gas permeability increases with increased temperature but for butyl rubber it is very low, up to 70-80 ^{0}C.
- Low glass transition temperature.
- It displays high damping at ambient temperatures.
- It has good ozone resistance.
- This rubber also has good weathering, heat and chemical resistance.
- It has good impermeability and stability.
- It is not suitable for use in contact with mineral oils.

3.5.2 Grade

Table 9 shows the various grades of butyl rubber.

Table 9 Grades of Butyl Rubber

Grade	Unsaturation (Ave. mole%)	Mooney Viscosity (ML @ 125°C)
Butyl 065	Low (0.7 to 1.1[a])	Low (29-35)
Butyl 068	Low (~1.0[a])	High (46-56)
Butyl 165	Medium (1.1 to 1.5[a])	Low (29-35)
Butyl 268	High (1.5 to 1.8[a])	High (46-56)
Butyl 365	High (2.0 to 2.6[a])	Low (30-36)

[a] Grade stabilized with non-staining antioxidant

3.5.3 Aeronautical Application

Table 10 shows the Aeronautical Applications of butyl rubber.

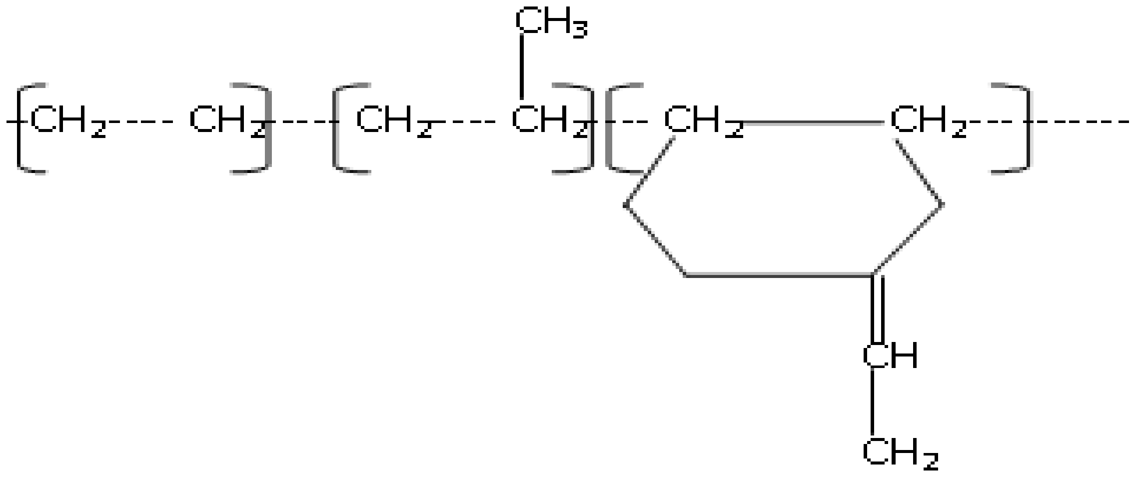
Table 10 Aeronautical Applications of Butyl Rubber

S. No.	Rubber Compound	Governing Specification / TA number	Component Part No. / Part Name	Project
1	Butyl rubber	NFL-17-101A-40B7	M 21468 (6800-R70-35)/sleeve/rubber boot	Jaguar
2	Butyl rubber	NFL-17-101A-40B7	M 21471 (6800-R70-51) /sleeve/rubber boot	Jaguar
3	Butyl rubber	NFL-17-101A-40B7	M 21477 (6800-R70-44.5)/sleeve/rubber boot	Jaguar

3.6 Ethylene Propylene Diene Monomer (EPM, EPDM)

3.6.1 Structure

EPDM (Ethylene Propylene Diene Monomer/M-class) rubber, a type of synthetic elastomer, is used for wide range of applications. The “M” class includes rubbers having a saturated chain of the polymethylene type (as per ASTM standard D-1418). The diene(s) currently used in the manufacture of EPDM rubbers are DCPD (dicyclopentadiene), ENB (ethylidene norbornene) and VNB (vinyl norbornene). The molecular structure is represented below.



The ethylene content is around 45 to 75%. The higher the ethylene content, higher is the loading possibilities of the polymer (with filler such as silica or carbon black), better mixing and extrusion. During peroxide curing, these polymers give a higher crosslink density. The amorphous polymer (less ethylene content) exhibits considerable ease of processing, which is mainly influenced by molecular structure. The dienes, typically, between 2.5 wt% up to 12 wt%, of the composition serve as crosslinks, which provide resistance to unwanted tackiness, creep or flow during end use.

3.6.2 Properties

The properties of EPDM are depicted below:

- This rubber has excellent resistance to atmospheric ageing and oxygen.
- It has good ozone resistance
- It has good resistance to most water-based chemicals
- It also has resistance to vegetable-based hydraulic oils
- It has however very poor resistance to mineral oils and di-ester based lubricants
- This rubber has stable, saturated polymer backbone structure
- It has excellent resistance to heat
- It has good electrical resistivity
- The EPM or EPDM rubber is also resistant to polar solvents like water, acids, alkalies, phosphate esters and many ketones and alcohols
- **Heat resistance** Up to 150°C
- **Cold flexibility** Down to approximately -57°C
- **Chemical resistance to**
  - Hot water and steam up to 149°C with special compounds up to 204°C
  - Glycol based brake fluids up to 149°C
  - Many organic and inorganic acids
  - Cleaning agents, soda and potassium alkalis
  - Phosphate-ester based hydraulic fluids (HFD-R)

• Silicone oil and grease

• Many polar solvents (alcohols, ketones, esters)

• Ozone, aging and weather resistant

- **Not compatible with:**

• Mineral oil products (oils, greases and fuels)

3.6.3 Grade

Various grades of the rubber are tabulated in Table 11.

Table 11 Grades of EPDM

Rubber	Country	Producer	Trade names
EPM and EPDM	Italy	Montesud Petrochmica	Dutral N, EPM, EPDM
	Netherlands	Netherlandse staatsmijnen	Keltan
	UK	International synthetic rubber	Intclan
	USA	Dupont	Nordel
	India	Unimers India ltd.	Herlene H512, H563

E7502 70 Shore	• Excellent surface finish • Outstanding chemical stability in polar fluids and steam • Ideal for custom designed parts
E7518 70 Shore	• Outstanding chemical stability in polar fluids and steam • Ideal for high volume applications
E8502 80 Shore	• The same properties as E7502 but with a hardness of 80 shore A providing higher extrusion resistance

3.6.4 Aeronautical Application

Aeronautical Applications of EPDM are given in Table 12.

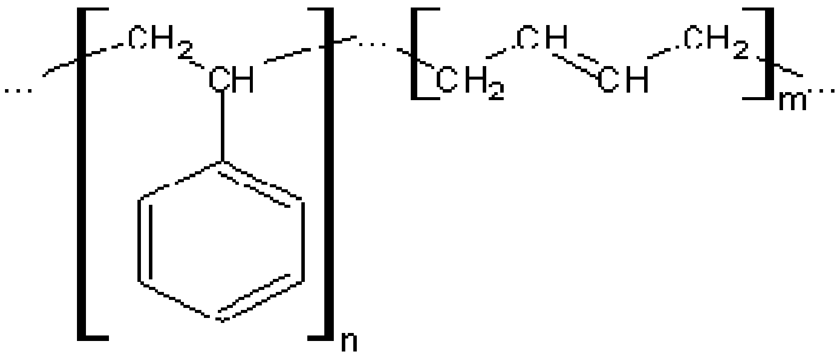
Table 12 Aeronautical applications of EPDM

S. No.	Rubber Compound	Governing Specification / TA number	Component Part No. / Part Name	Project
1	EPDM	HM 4927/ 995	201P 321H 1000 207/H / FORWARD RUBBER BUSH	ALH

3.7 Styrene Butadiene Rubber (SBR)

3.7.1 Structure

Styrene-Butadiene or Styrene-Butadiene-Rubber (SBR) is a synthetic rubber copolymer consisting of styrene and butadiene. The molecular structure is depicted below:



SBR can be produced from solution or as emulsion. In both instances, the reaction is via free radical polymerization. Pressure reaction vessels are required and usually charged with the two monomers, a free radical acid and a chain transfer agent such as an alkyl mercaptan. The latter prevents high molecular weight and high viscosity product from forming. High styrene-content rubbers are hard, since the T_g (glass transition temperature) of butadiene is extremely low. The production process is initiated by sodium.

3.7.2 Properties

The properties of SBR are given below:

- This type of rubber is usually very weak unless reinforcing fillers are incorporated. With suitable fillers, this becomes a strong rubber.
- It has similar chemical and physical properties like natural rubber.
- It has better abrasion resistance.
- It has poorer fatigue resistance.
- Heat resistance is better than natural rubber.
- Low temperature flexibility and tensile strength are less than that of natural rubber.

3.7.3 Grade

Various grades of the SBR are listed in Table 13.

Table 13 Grades of SBR

Rubber	Country	Producer	Trade names
Emulsion SBR	France	Firestone – France Elastomer Polymer corpn Compagnie Francaise des produits chimiques shell	FR-S Ugitex S Polysar Krylene Krynol Cariflex S

	Italy	ANIC	Europrene
	Netherlands	Chemische Industrie AKU-Goodrich Shell Nederland chemie	Hycar Ciago Cariflex S
	W. Germany	Bunaweke Huls	Buna Huls Duranit
	UK	Synthomer Chemie Doverstrand	Synthomer revinex butakon
		International synthetic rubber	Intol Intex
Solution SBR	Belgium	Petrochim	Solprene
	Spain	Calatrava, Empresa la Industria Pwtoquimica	Solprene
	UK	International synthetic rubber	Unidene

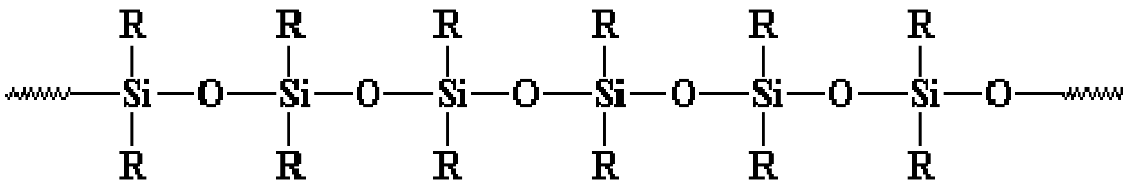
3.7.4 Aeronautical Application

SBR is generally used in manufacturing of aircraft tyres.

3.8 Silicone Rubber (SiR)

3.8.1 Structure

Silicone rubber is a polymer that is a "backbone" of silicon-oxygen linkages, the same bond, as shown below is found in quartz, glass and sand. "R" stands for whatever molecules might be attached to the backbone. For example, if -CH_3 (methyl) groups attach to the silicon atoms, the polymer is called polydimethylsiloxane. It's the most common silicone. Silicones make good elastomers because the backbone chain is very flexible. The bonds between a silicon atom and the two oxygen atoms attached to it are very flexible. The angle formed by these bonds can open and close like a scissors without much trouble. This makes the whole backbone chain flexible.



Normally, heat is required to vulcanize (set) the silicone rubber which is a two stage process. Initially silicone rubber is moulded to the desired shape and then post-cured for a prolonged period.

3.8.2 Properties

The important properties are described below:

- The outstanding property of this form of rubber is its very wide temperature range. It offers excellent resistance to extreme temperatures, the range of which can be from -38°C to +260°C
- It has better oil and water resistance than the others

- Because of its compatibility with varied temperature range, the tensile strength, elongation, tear strength and compression set of this rubber can be far superior to conventional rubbers
- It is resistant to ozone, UV, heat and other aging factors
- This rubber is resistant to steam
- It is metal detectable
- It glows in the dark
- It is electrically conductive
- It is resistant to chemical/oil/acid/gas
- It has low smoke emission and flame retardant
- Appropriately cured silicone has extra-ordinary low compression set

3.8.3 Grade

Various grades of silicone rubber are depicted in Table 14.

Table 14 Grades of Silicone Rubber

Supplier	Trade name and Grade	Polymer type	Description and applications
Gums – raw polymers without compounding or curing ingredients			
ICI	E301	SI	Devolatilised gum for general purpose stocks; benzoyl peroxide cured
	E303	VSI	Low vinyl devolatilised gum for general purpose stocks; low compression set stocks
	E351	PVSI	Low vinyl devolatilised gum, with extreme low-temperature flexibility
Base, semi- compounded stocks			
ICI	E367	VSI	Pyrogenic silica loaded stock to take filler addition for extrudable and low-cost rubbers
Midland Silicones	Polysil 2432	VSI	Low filler content for compounding to 30-80 IRHD Rubbers
Fully compounded stocks			
ICI	E313	VSI	General purpose range, 50-80 IRHD for extrusions, moulding, electrical sleeving and cables
	E342	VSI	60-80 IRHD, with good oil resistance and compression set for sealing applications

	E361	PVSI	High strength 50 IRHD mix for sleeving and aircraft moulding
	E323	VSI	Heat resistant grade 50 IRHD for extrusions and mouldings resist 300^0C for short periods
	E343	VSI	80 IRHD grade for oil seals
	E330	VSI	50-80 IRHD range, vulcanized with vinyl specific peroxide: requires no post cure
Midland Silicones	Silastomer 2451-5	VSI	Easy processing 40-80 IRHD range with good heat stability
	2461-5	PVSI	Extreme low temperature 40-80 IRHD range, for moulding
	2472-5	VSI	50-80 IRHD range with low compression set, good heat oil resistance: low shrinkage
	2801U	VSI	50 and 70 IRHD rubbers with high strength and resilience: also high flex resistance
	2438U	VSI	No post cure 70 IRHD grade: excellent compression set and oil resistance
	2457	VSI	Non milling palletised cable insulation grade: steam or hot- air curable
	2811U	VSI	Translucent 50 IRHD grade for medical, Pharmaceutical and food applications
Dow Corning	Silastic 35, 55,75U	VSI	High Performance tough abrasion- resistant grades for general purpose applications
	5503/5/7U	VSI	Translucent grades for Medical, pharmaceutical and food applications
	2351U	PVSI	High strength flame retardant grade for aircraft door and window seals
	745-8U	VSI	No post cure grade with low compression set suitable for injection molding.

3.8.4 Aeronautical Application

Figure 2 and Table 15 illustrates the Aeronautical Applications of silicone rubber.

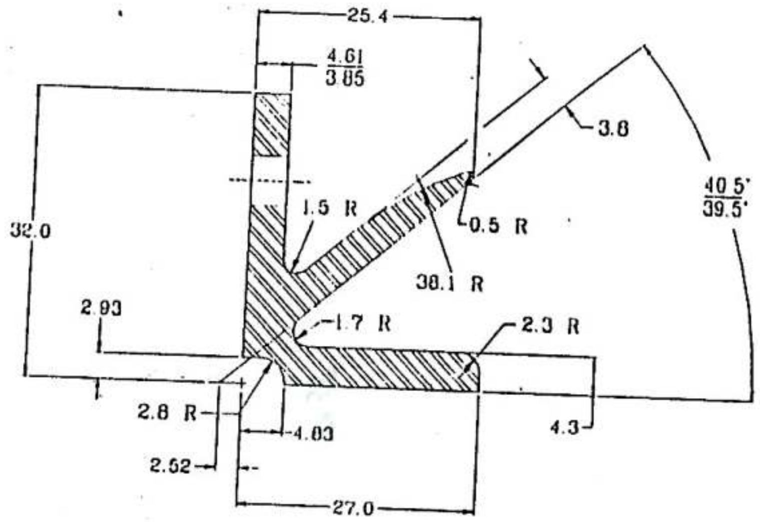


Figure 2 K seal for LCA

Table 15 Aeronautical Applications of Silicone Rubber

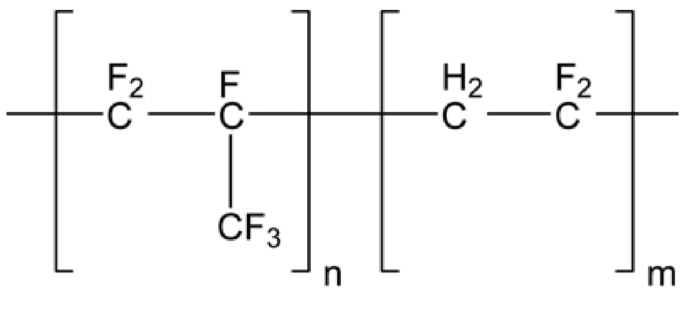
Project	**Part No.**	**Part Name**	**Material Spec.**
Adour	AX 56265/H	Seal ring	MSRR 9453
Dart	COM 6287/H	Seal ring	MSRR 9453
Orpheus	SH 70-A4	`O'seal	BACE430
Ch/Ck	3130-26-21-556/H	Rubber seal	50D6
Ch/Ck	3160-73-39-002/H	Gasket	50D7
Jaguar	R 6a/H	Rubber seal	50D7
Jaguar	R 30PB 701/H (M 20872)	`O'ring	50D7
Jaguar	R 38 SL 1013/H (M 20874)	Rubber`O'ring	50D7
Jaguar	RN 22/H	Rubber`O'ring	50D7
Jaguar	RN 29/H (M 20885)	`O'ring	50D7
Jaguar	020 A4/H (M 20880)	Rubber`O'ring	50D6
Jaguar	025 A4/H	Rubber`O' ring	50D6
Jaguar	032 A4/H (M 20881)	Rubber`O'ring	50D6
Jaguar	121E-23-125-081/H	Pad	50D7
Jaguar	121E-23-125-082/H	Pad	50D7
Kiran	M 20588-2	Rubber`O'ring	50D6
HS 748	HS 748-4911	Bush	50D6
HS 748	HS 748-4913	Rubber pad	50D6
DORNIER	DO 228-8087/A	Rubber sheet	50D5
Aircraft/ Helicopter	150- 30303	Canopy Seal	HM 4922
Aircraft/ Helicopter	201X 530H 0000 802	Door Seal	HM 4922
Aircraft/ Helicopter	201X 530H 0000 807	Elastoflex seal	HM 4922

Aircraft/ Helicopter	3.1133c	Metallic bellow	HM 4922
Aircraft/ Helicopter	M 7275	Washer	HM 4923
Aircraft/ Helicopter	4MX6M	Autoclave gasket	HM 4923
Aircraft/ Helicopter	01K 2K 2010 002 1R	Rubber Chord	DTD 5531 Gr 70
Aircraft/ Helicopter	01K 2K 2010 002 1RA	Rubber Seal – LH	DTD 5531 Gr 70
Aircraft/ Helicopter	01K 2K 2010 002 1RA	Rubber Seal – LH	DTD 5531 Gr 70
Aircraft/ Helicopter	01K2G1140001 1GO	Rubber Seal – LH	DTD 5531 Gr 70
Aircraft/ Helicopter	1216-71-131-52-0	Sleeve	50D7
Aircraft/ Helicopter	6800-S70-51	Sleeve	EE 50D7
Aircraft/ Helicopter	50D7/SIL 1013	Rubber Tube	EE 50D7
Aircraft/ Helicopter	121S – 23 – 860 – 1013	Gasket	EE 50D7
LCA	LCA-P-576	K-seal	HM 4923

3.9 Fluorocarbon Elastomer (FKM)

3.9.1 Structure

Peroxide-curable fluorocarbon elastomers having interpolymerized units derived from a cure site monomer containing bromine or iodine. The fluorocarbon elastomer gums are prepared by copolymerizing with the principal monomers normally used in preparing fluorocarbon elastomers, e.g. vinylidene fluoride, hexafluoropropene and (optionally) tetrafluoroethylene, a small amount of a novel cure site monomer which is a vinyl ether in which at least one of the two vinylic (or double-bonded) carbon atoms thereof is bonded to atleast one bromine or iodine atom. The molecular structure is shown below:



The cured fluorocarbon elastomers of this invention have useful properties such as acid resistance, thermal stability and high tensile strength. These properties of shaped articles made from these fluorocarbon elastomers are not adversely affected upon exposure to high temperatures for extended periods.

3.9.2 Properties

Fluorocarbon elastomer is normally not favorable for Low temperature resistance and for static applications is limited to approximately -26°C although in certain situations it is suitable down to - 40°C. Under dynamic conditions, the lowest service temperature is between -15 and -18°C.

Gas permeability is very low and similar to that of butyl rubber. Special FKM compounds exhibit an improved resistance to acids, fuels, water and steam.

Heat resistance

• Resistant up to 204°C (400°F) and, higher temperatures with shorter life expectancy.

Cold flexibility

• Down to -26°C (-15°F) (some to -40°C).

Chemical resistance to

- Mineral oil and grease, low swelling in ASTM oil No.1, No.2 and No. 3.
- Non-flammable synthetic hydraulic fluid (HFD).
- Silicone oil and grease.
- Mineral and vegetable oil and grease.
- Aliphatic hydrocarbons (fuel, butane, propane, natural gas).
- Aromatic hydrocarbons (benzene, toluene).
- Chlorinated hydrocarbons (trichloroethylene and carbon tetrachloride).
- Fuels, also fuels with methanol content.
- High vacuum.
- Very good ozone, weather and aging resistance
- They have excellent resistance to chemical attack by oxidation, by acids and by fuels.
- They have limited resistance to steam, hot water, methanol and other highly polar fluids.
- The outstanding heat stability and excellent oil resistance are due to the high ratio of fluorine to hydrogen, the strength of the carbon-fluorine bond and the absence of unsaturation.
- The latest FKM polymers have a much broader fluids resistance profile than standard fluoroelastomers.
- They are able to withstand strong bases and ketones as well as aromatic hydrocarbons, oils, acids and steam.
- Peroxide cured fluoroelastomers have inherently better water, steam and acid resistance

Not compatible with:

- Glycol based brake fluids.
- Ammonia gas, amines, alkalis.
- Superheated steam.
- Low molecular organic acids (formic and acetic acids).

3.9.3 Grade

Various grades of the Fluorocarbon rubber are shown in Table 16.

Table 16 Grades of Fluorocarbon Rubber

Producer	Trade name	Type	Mooney viscosity (approx)	Special features
Du Pont (USA)	Viton	A	65	General purpose
		AHV	160	High-strength vulcanisate : better low – temperature properties
		A35	35	Good flow in extrusion and moulding
		B	74	Superior resistance to heat, chemicals and solvents
		B50	50	Safe processing : good flow
		LM	Semi liquid	Processing aid
		E60	60	Low compression set : easy processing
M M M (USA)	Fluorel	2140	115	General purpose
		2141	90	Safer processing
		2146	30	Higher filler acceptance : processing aid
		2160	60	Low compression set : easy processing
Montecatini (Italy)	tecnoflon	SL	80	General purpose
		SH	110	General purpose
		T	90	Superior resistance to oils, chemicals and solvents

3.9.4 Aeronautical Application

Aeronautical Applications of Fluorocarbon Rubber are given in Table 17.

Table 17 Aeronautical Applications of Fluorocarbon Rubber

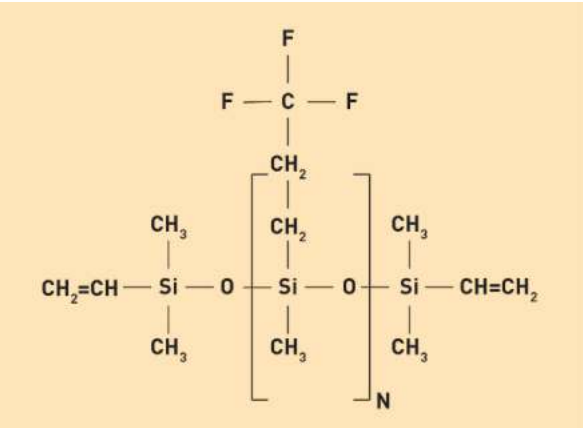
Project	Part No.	Part Name	Material Spec.
Artouste	9560144500-8	SEALING RING	60C7
Artouste	9682000851	`O' RING	60C7
Artouste	9682700892	`O' RING	60C7
ALH	201P 291H 1000 203/H	`O' RING	60C7
ALH	201P 291H 1000 204/H	`O' RING	"
ALH	201P 636H 0020 204/H	GASKET	60C7
ALH	201P 653H 0010 203/H	GASKET	60C7
ALH	201P 762H 1100 202/H	RUBBER BUSH	"
Ch/Ck	3130-46-10-566/H	RUBBER SEAL	60C7
Jaguar	CSP 4DE- 223/H	`O' RING	60C7
Jaguar	CSP 4DE- 226/H	`O' RING	"
Jaguar	CSP 4 HF-213/H	ELASTOMERIC`O'RING SEAL	"

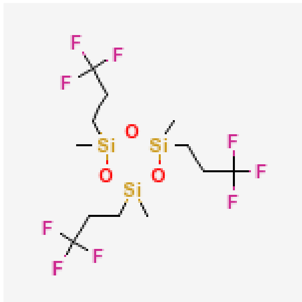
Jaguar	R 38C/H	`O' RING	60C7
Jaguar	R 33 DF-150/H (M 20876)	RUBBER`O'RING	60C7
Jaguar	121E-63-530-040/H	CABLE SEAL	60C7
Artouste	9560126790	SEALING RING	64C8
Artouste	9682201141	`O' RING	64C8
Adour	0260101040	SEAL RING	AMS 7280
ALH	201P 636H 0000 807/H	`O' RING	AMS7276A
Adour	EU 15573	SEALING RING	MSRR 9450
Adour	KB 21004	SEALING RING	MSRR 9450
Adour	KB 21018	SEALING RING	MSRR 9450
Adour	KB 21324	SEAL RING	MSRR 9450
Adour	KB 21016/H	SEAL RING	MSRR 9450
Dart	AU 9133	SEALING RING	MSRR 9450
Dart	BR 37224	SEALING RING	MSRR 9450
Dart	RK 33357	RING SEALING	MSRR 9450
Dart	RK 50303	SEALING RING	MSRR 9450
ALH	201P 636H 0000 807/H	`O' RING	AMS7276A

3.10 Fluorosilicone (FVMQ)

3.10.1 Structure

The molecular structure is depicted as shown below:





MQ: methyl group

PMQ: phenyl and methyl groups

VMQ: vinyl and methyl groups

PVMQ: phenyl, vinyl and methyl groups

These polysiloxanes have relatively low tensile and elongation properties when reinforced, but these properties are retained after aging under a variety of service conditions. Silicone compounds are resistant to heat, high-aniline point oils, atmospheric conditions, ozone and compression set. Electrical properties are excellent. Specific properties can be optimized, but all of the desired properties are not available in the same compound. Some versions require a post-cure to develop optimum properties. FVMQ contains trifluoropropyl groups next to the methyl groups.

3.10.2 Properties

The various properties of Fluorosilicone rubber are described below:

Heat resistance

• FVMQ is a high-end rubber offering outstanding aging properties over a temperature range of -58°F to +392°F

Cold flexibility

• Down to approximately -73°C (-100°F)

Chemical resistance

• Aromatic mineral oils (IRM 903 oil)
• Fuels
• Low molecular weight aromatic hydrocarbons (benzene, toluene)

3.10.3 Grade

Various grades of the Fluorosilicone rubber are illustrated in Table 18.

Table 18 Grades of Fluorosilicone

Supplier	Trade name and Grade	Polymer type	Description and applications
Dow Corning	Silastic 422	FVSI	For fuel and oil resistant aircraft seals and electrical sleeving
	Silastic LS53, 63U LS2311U LS2332U	FVSI FVSI FVSI	Fuel-Oil resistant grades for seals High Modulus fluorosilicone grade for O - rings High strength and tear strength for shock mountings, sleeving and seals

3.10.4 Aeronautical Application

Table 19 shows the Aeronautical Applications of Fluorosilicone rubber.

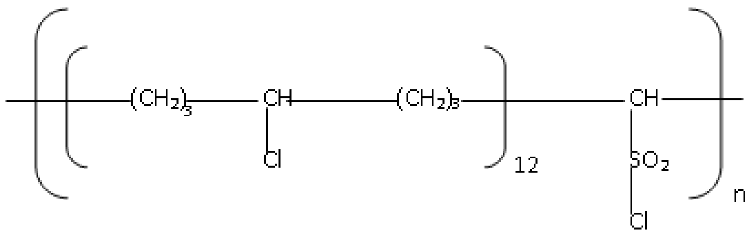
Table 19 Aeronautical Applications of Fluorosilicone

Project	Part No.	Part Name	Material Spec.
HPT 32	HPT 32 -5069	`O' RING	EE61 D6
Aircraft/ Helicopter	M 21439	Rubber Profile	EE61 D6
Aircraft/ Helicopter	M 5859	Rubber Boot	EE61 D6
Aircraft/ Helicopter	LN 9490 & LN 9491	Cushion Clamp rubber	MIL 25988B Class I Gr 60

3.11 Chlorosulphonated Polyethylene/ Hypalon (CSM)

3.11.1 Structure

When polyethylene is reacted in solution with chlorine and sulphur dioxide it is transformed to a vulcanisable rubber, chlorosulphonated polyethylene, is described as a CSM rubber. The basic structure of CSM may be represented as below:



Typical values for a general purpose CSM are n=17; variation of the amount and location of the chlorine and sulphonyl chloride groups gives products having a range of chemical and physical properties. Hypalon is a trademark for chlorosulphonated polyethylene synthetic rubber noted for its resistance to chemicals, temperature extremes and ultraviolet light. It is a product of DuPont. Hypalon has become the common name for all kinds of CSM, even though DuPont is not the only manufacturer. Tosoh Corporation of Japan produces CSM under the trade names Toso-CSM and Extos.

3.11.2 Properties

The properties of the Chlorosulphonated polyethylene are described below:

- Tensile strengths of CSM vulcanisates range from 35 kgf/cm^2 to 200 kgf/cm^2
- Heat resistance upto 150^0 C
- Resistance to wide range of aggressive chemicals (including hydrogen peroxide, calcium hypochloride and sulphuric, chromic and nitric acids), ozone and oxidative ageing
- Intermediate oil and solvent resistance depending on the chlorine level
- Electrical insulating properties
- Low flammability characteristics
- Excellent resistance to abrasion, flex and mechanical abuse

3.11.3 Grade

Various grades of the rubber are tabulated in Table 20.

Table 20 Grades of Hypalon

Type	Mooney viscosity	Special properties and application
Hypalon-20	30	for flexible solution coatings and for blending to upgrade other Elastomers

Hypalon-30	30	for stiffer solution coating
Hypalon-40	45,55,115	easy processing, for general moulding, extrusion and calendaring
Hypalon-45	40	easy processing, higher modulus, can be used without curing
Hypalon-48	50	higher chlorine content, greater solvent resistance

3.11.4 Aeronautical Application

Figure 3 shows the Aeronautical Application of Hypalon rubber.

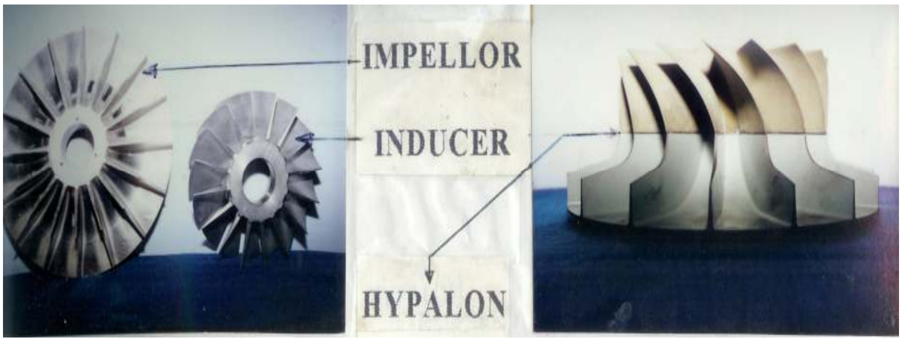


Figure 3 Hypalon as a bonding agent

Hypalon to specification HM 4926 issue E is used as a bonding agent in Artouste III B engine as shown in Figure 3.

4 RUBBER COMPOUNDING INGREDIENTS

Compounding, a term that has evolved within the rubber industry, is the material science of modifying a rubber or elastomer or a blend of polymers and other materials to optimize properties to meet a given service application or set of performance parameters. Compounding is therefore a complex multidisciplinary science necessitating knowledge of materials physics, organic and polymer chemistry, inorganic chemistry and chemical reaction kinetics. The materials scientist, when designing a rubber formulation, has a range of objectives and restrictions within which he has to operate. Product performance requirements will dictate the initial selection of formula ingredients. These materials must be environmentally safe, meet occupational health and safety requirements, be processable in the product manufacturing facilities and be cost effective.

Compounded rubber has many unique characteristics not found in other materials, such as dampening properties, high elasticity and abrasion resistance. Hence rubber has found use in applications such as tires, conveyor belts, large dock fenders, building foundations, automotive engine components and a wide range of aeronautical application. The ingredients available to the materials scientist for formulating a rubber compound can be divided into five categories (Table 21):

Table 21 Compounding Ingredients

1. Polymers	Natural rubber, synthetic polymers
2. Filler system	Carbon blacks, clays, silicas, calcium carbonate
3. Stabilizer system	Antioxidants, antiozonants, waxes
4.Vulcanisation system	Sulphur, accelerators, activators
5. Special materials	Secondary components such as pigments, oils, resins, processing aids and short fibers

4.1 Basic Factors Responsible For Reinforcement

4.1.1 Particle size

Fine particles have much greater effect on reinforcement than coarse particles. This is directly related to the reciprocal of surface area per gram of filler. In other words the effect of small particles reflects their greater extent of interface between polymer and solid materials. The size and shape of the particles of the fillers may be different in different fillers like spheroidal, cubic / prismatic, tubular, flaky or elongated. It has been established that farther away is the shape of the particles from spherical the greater is the reinforcement. The particle size may be measured either by electron microscope, by sieve (for large particles) or by light reflectance. In light reflectance method, the amount of reflected light diminishes with smaller particles.

4.1.2 Surface area

Surface area is one of the most important filler properties. Many effects of fillers are surface area dependent specially surfactants, dispersants. Polar polymers are reacted with the filler surface. Surface area is generally measured by gas adsorption method.

4.1.3 Specific Surface Activity / Chemical Composition

The nature of a solid particle may be varying in a chemical sense having different chemical groups like hydroxyl, metal oxide etc. Some Elastomers of polar nature (Nitrile, Neoprene, etc.) will interact more strongly with such filler surface having OH, COOH or chlorine atoms. Chemical group surface also play an important part on the rate of cure with many vulcanising systems.

4.2 Reinforcing Ingredients

4.2.1 Fillers

Fillers are used to modify or enhance properties such as thermal conductivity, electrical resistivity, friction, wear and flame resistance. There are two basic types of fillers: conductive fillers and extender fillers. Conductive filler is used to increase electrical and thermal conductivity. Extender filler is used to reduce material costs. Fiber reinforcement significantly affects the properties of the compounds to which they are added. Reinforcements are specialized particulates, fibers or fabrics used to strengthen or toughen plastic, metals or ceramics. Filler can be defined as an inert mineral powder of high specific gravity (2.00-4.50). It is used in rubber mixtures to provide certain degree of stiffness and hardness and to decrease cost. Examples are calcium carbonate (whiting), barytes, silicates, glass spares and clay, etc.

The practical aspects of the rubber product made out of different non-black fillers of the above characteristics are shown in Table 22.

Table 22 Characteristics of Non Black Fillers

Sl No	Characteristics	Results (Vulcanisate)
a.	Smaller particle size	Higher Tensile Strength Higher abrasion resistance Higher electric conductivity (black) Higher Mooney viscosity
b.	Increase in surface activity (adsorption)	Higher modulus of high extension Higher abrasion resistance Higher adsorptive properties Low hysteresis
c.	Increase in structure (anisometry)	Lower extrusion shrinkage, Higher Mooney viscosity Higher hysteresis Longer incorporation time

4.2.1.1 Carbon Black

Carbon blacks are essentially elemental carbon and are composed of particles which are partly graphitic in structure. The carbon atoms in the particle are in layer planes which, by parallel alignment and overlapping, give the particles their semi graphitic nature. The outer layers are more graphitic than those in the centre. The particles range in size from 10 nm to 400 nm in diameter, the smaller ones being less graphitic. To meet multiple requirements of rubber trade, more than 20 grades (Some are shown in Table 23) are available in the market. Carbon black can be manufactured by various methods while the three main processes are the channel process, furnace process and thermal process; yielding channel black, furnace black and thermal black, respectively. Certain partial combustion processes are also known. Carbon blacks when compounded into rubber provide stocks with high electrical resistance and in some cases impart good conduction properties. Channel black is characterized by lower pH, higher volatile content and less chain like structure between the particles. Its chief use is as reinforcing agent for rubber. It increases both abrasion and oil resistance. The five most important properties of carbon blacks are particle size, structure, physical nature of the surface, chemical nature of the surface and particle porosity.

Table 23 Grades of Carbon Black

ASTM grades	N110, N115, N121, N220, N234, N326, N330, N339, N347, N351, N375, N539, N550, N650, N660, N683, N762, N765, N772, N774, ACB2000, ACB5000
New grades	N134: superior abrasion resistance N231: low structure, high abrasion resistance ACB1000: low structure, high tensile strength, high reinforcement, resistant to tear and chipping in natural rubber compounds
Customised grades	N234 for Bridgestone and Goodyear N347 for Michelin N550 for Goodyear

Carbon black is the most important filler for carbon-backboned rubbers. In general terms, the smaller the particle size, poorer the processability and higher the reinforcement. Reinforcement is meant by the enhancement of tensile strength, abrasion resistance and tear resistance. Carbon black particles with pores and cracks have higher surface areas than blacks of similar particle size without such features.

4.2.1.2 Non – Black Reinforcing Fillers

These are mainly used in white or light coloured compounds where reinforced mechanical properties are required. In order of their reinforcing properties the whole range of non-black fillers are given below:

I) Activated silica (Pyrogenic or ppt. SiO_2)
II) Activated aluminium silicate.
III) Activated calcium silicate.
IV) Activated calcium carbonate.
V) Magnesium carbonate.

The above materials are obtained in different forms and grades under different trade names having varying degree of reinforcements according to the method of manufacture. For example silica (silicon dioxide) may have different reinforcing properties according to whether the fillers have been manufactured by pyrogenic or precipitation method.

4.2.1.3 Silica (Pyrogenic or Fumed)

It is generally manufactured by hydrolysis of silicon tetrachloride in an oxy-hydrogen flame.

$$2\ H_2 + O_2 + SiCl_4 \longrightarrow SiO_2 + 4\ HCl$$

A homogenous mixture of silica vapour, hydrogen and air is burned in a cooled combustion chamber. Particle size and surface structure are controlled by the $SiCl_4$ concentration, flame temperature, variation of the amount of inert gas in the flame. Special properties of silica include: -

i) Thickening and thixotropic effects for liquids.
ii) Antisegmentation agent.
iii) Reinforcing effect on elastomer.
iv) Antiblocking agent in plastic filament.
v) Good dispersability.

4.2.1.4 Silica – SiO_2 (Perculated – Wet Method)

Precipitated silica is produced by chemical leaches in a water solution and that is why classed a wet process. It is produced by the chemical reaction of sodium silicate and a mineral acid like sulphuric acid. From the solution it is precipitated as ultrafine particles.

The process flowchart is given below:

Sodium silicate solution

Add dilute $H_2\ SO_4$ / HCl ⟶ Precipitation (Maintain proper pH)

Wash centrifuge ⟶ Drying ⟶ Refining ⟶ Packing

In the end, product controls are exerted on pH, moisture fineness and SiO_2 content.

4.2.1.5 Aluminium / Calcium Silicate

Next to precipitated silicas comes the different type of silicates like Al-silicate, Ca – silicate, etc. These are all reinforcing fillers imparting good hardness and other physical properties to NR, SBR stocks. It gives about 60-70% of reinforcement of precipitated silicas. It can be used in all types of non-black rubber stocks. In the case of Ca-silicate, care should be taken to off set the scorching behaviour of the fillers due to high moisture absorption of the filler from atmosphere, especially in rainy season.

4.2.1.6 Activated calcium carbonate

This is manufactured by the precipitation of extremely small crystals of calcium carbonate under carefully controlled condition in the presence of stearic acid. So chemically it is stearic coated calcium carbonate. It is a white odourless fine powder of approximately 2.5 Specific Gravity. It contains about 2% of stearic acid.

It is mainly used as semi-reinforcing fillers particularly in those products where hot tear resistance is very important factor. It disperses very quickly in rubber stock and has got good extruding properties. It is mainly used in hot water bottle, stoppers, footwear components, cycle tyres and tubes and other moulded products.

4.2.1.7 Magnesium carbonate

When good reinforcing non-black fillers like precipitated silica were not developed, magnesium carbonate was the only semi – reinforcing filler widely used in rubber industry. It gives fairly good reinforcement up to 20 parts of loading. It is made available now as non-toxic, fluffy, white power of about 2.2 specific gravity and various particle sizes. It gives good resilient stock needs adjustment of formula property. It also gives good transparent compounds.

4.2.1.8 Fillers

Inert fillers do not give sufficient reinforcement and are used to adjust the volume and processability. These inert fillers are china clay (soft and hard varieties), calcium carbonate (whiting), talc, barytes, zinc oxide, lithopone, magnesium silicate.

4.2.1.8.1 China clays

It is obtained by suspending some crude minerals in water and passing through a series of silting tanks until it is free from grit and other coarse materials. Washing is continued till a clean material is obtained. The material is then dried to a moisture content of 1% and milled in a Raymond mill to the required fineness.

It is a naturally occurring material and consequently differs widely in chemical composition depending on the source but basically consists of mixture of hydrated aluminium silicate, quartz, feldspar, etc. Various grades of clays are available depending on the colour, fineness and reinforcing qualities. According to the reinforcing properties, clay may be termed as soft or hard. Soft clays are mainly used as inert filler. On the other hand, hard clays give moderately good hardness as that of aluminium or calcium silicate but lacks in other properties like Tensile Strength (TS), abrasion, etc. Its main uses are in all modeled products, battery boxes, extruded strips, tubing, etc.

4.2.1.8.2 Calcium carbonate (Whiting)

It is obtained either by –

i) Crushing crude materials like limestone marbles or chalks or by
ii) Levigation process.

Various types of whiting are available depending on colour, fineness and manufacturing process, particulate size, etc. It is an odourless, non –toxic, white powder of Sp.Gr. 2.65-2.95. It is primarily used as inert filler and has got effect on curing.

4.2.1.8.3 Other Inert Filler

Other categories of the inert fillers are shown in Table 24.

Table 24 Inert fillers of other category

Barytes	Barium sulphate
Blanc Fixe	PPR barium sulphate
Talcum powder	Hydrated magnesium silicate inert filler, dusty powder.
Lithopone	A mixture of barium sulphide and zinc sulphate. Mainly used as inert filler as well as white pigment. Makes the rubber stock very heavy due to its high S. G. In using lithopone, the compounds must ensure that there is no free sulphur in it.
Zinc oxide	When used in higher dose, it acts as an inert filler and white pigment. It gives the rubber stock good heat ageing properties White zinc oxide was the only pigment available when pigment like titanium dioxide was not developed. It has got good adhesive property which is utilized in rubber cements.

A rubber compounder finds it quite difficult to incorporate or mix the fillers (both reinforcing and inert) in to the rubber, though sufficiently peptised before hand, until the base (i.e., the rubber compound before adding the filler) is sufficiently soft. This is because of the fact that the intermolecular forces of rubber i.e. Vander Waal's force resist the entry of the fillers. Here comes the role of some ingredient chemicals which make the intermolecular chains slippery by weakening the intermolecular forces of attraction and allow any subsequent material to enter into it. These chemicals are called plasticizers or softeners.

4.2.2 Plasticisers, Softeners and Extenders

These materials are added to rubber compounds primarily to aid the processing operations of mixing, calendaring, extruding and moulding.

4.2.3 Peptisers

Peptisers are used to increase the efficiency of mastication of rubbers i.e., to increase the rate of molecular breakdown, particularly in natural rubber, where usage is normally less than 0.5 pphr. Higher loadings are usually required in synthetic rubbers. Peptisers are added to rubber at the start of mastication and other compounding ingredients only when mastication has been taken to the required stage. Sulphur inhibits their action.

The effectiveness of a peptiser increases as the mastication temperature is increased. Peptisers normally have no effect on the properties of the vulcanisate.

4.2.4 Process oils and Extenders

In contrast to peptisers, petroleum oils and petroleum jelly function in a physical rather than a chemical manner and their effect is not dependent on the temperature of mixing. 5 to 10 pphr of these acts as a plasticizer during processing, causing a reduction in viscosity and easing filler incorporation. Petroleum oils are used as extenders to reduce the cost of rubber compounds. They may be incorporated during the manufacturing of certain polymers like oil extended SBR and EPDM or may be added during compounding, together with substantial quantities of fillers to offset their softening effect on the vulcanisate. The types of oils used as processing aids and extenders are broadly classified under the headings of paraffinic, naphthenic and aromatic. Aromatic oils give best processability but are likely to have detrimental effects on staining, colour stability and ageing resistance. Paraffinic oils are usually less effective as process aids, but have little effect on ageing performance, contact staining, or colour stability. Performance at low temperatures is also better than that of aromatic oils. Naphthenic oils fall between aromatic and paraffinic in their effects on performance of rubber.

4.2.5 Resins

4.2.5.1 Coumarone resins

Coumarone resins are manufactured by polymerization of styrene, coumarone indene and related materials occurring in certain fractions of coal tar. By controlling reaction conditions, a range of resins can be produced which vary in appearance from thick viscous liquids to hard clear resinous solids and in colour from dark brown to pale straw.

Both solid grades, with melting points in the range 65 -110°C and liquid grades are used as tackifiers and plasticizers, particularly in synthetic rubbers. The liquid grades usually impart greater tack. Both grades also help to restrain bloom from uncured and cured rubbers. Solid grades of Coumarone resins are essential in non-black SBR compounds for optimum physical properties.

4.2.5.2 Petroleum Resins

Petroleum resins are similar in general characteristics and applications to solid coumarone-indene resins. They are manufactured by polymerization of olefins in steam-cracked heavy –hydrocarbon petroleum fractions.

4.2.6 Special purpose Additives

4.2.6.1 Chemical Blowing Agents

In the manufacture of cellular rubbers from solid rubber, many types of chemicals are used. The most commonly used is sodium bicarbonate, though ammonium carbonate and bicarbonate are still in use. These liberate essentially carbon dioxide and yield an open pore structure.

4.2.6.2 Flame retardants

Flame proofing, or at least reduction of the fire hazards, is achieved by the use of mixtures of inorganic and organic materials in rubber compounds. Antimony trioxide and chlorinated derivates of paraffin hydrocarbons provide the most used combination, though zinc borate is also frequently included. The inherent flame resistance of polycholoroprene rubbers is improved by the addition of antimony trioxide.

4.2.6.3 Antioxidants

Ageing properties of raw rubber differ from vulcanized rubber because of latter's specific network structure and extra network material. Again this specific network structure can be determined by the choice of acceleration system and the curing conditions. Commercially available antioxidants for rubber may be divided into two classes:

i. Aminic (Secondary): Aminic type of antioxidants are strongly effective against flex, heat, ozone, etc., they are highly staining and cannot be used for white or coloured articles.

ii. Phenolic: Phenolic types of antioxidants are non-staining and non-discolouring antioxidants and can be used in white or coloured product. Their efficiency giving protection against ageing is much lower compared to aminic type of antioxidants.

4.2.6.4 Antiozonant

These are the substances used to reverse or prevent the severe oxidizing action of ozone, on Elastomer, both natural and synthetic. Antiozonants used are petroleum waxes, both amorphous and microcrystalline, secondary amines such as N, N-diphenyl-para-phenylenediamine, quinoline and furan derivatives.

4.2.7 Vulcanising Agents

Vulcanising agents are necessary for vulcanisation. Without the chemical crosslinking reactions, no improvements in the physical properties of the products could be achieved.

These are the chemicals that are required to crosslink the rubber chains into three-dimensional network which gives the desired physical properties on the final product. The type of crosslinking agent required will vary with the type of rubber used; however, they can usually be grouped in the following categories.

4.2.7.1 Sulphur and Related Elements

Most common rubbers such as Natural, Butyl and Polyisoprene are of general purpose type. Vulcanisation with sulphur is possible with these rubbers as they contain unsaturation and hence sulfur is the most common vulcanising agent used. Two forms of sulphur, the rhombic and amorphous (or insoluble sulphur), are compared in Table 25 with selenium and tellurium.

Table 25 Comparison of Elemental Vulcanisation Agents

	Rhombic	Amorphous	Selenium	Tellurium
Atomic weight	32.06	32.06	78.96	127.61
Appearance	yellow powder	yellow powder	metallic powder	metallic powder
Specific gravity	2.07	1.92	4.80	6.24
M.P. °C	112.8-119	>110	217.4	449.8

The rhombic form is normally used for vulcanization. It exists as a cyclic (ring) structure composed of eight atoms of sulphur, S_8. The amorphous form is actually polymeric in nature; it is a meta stable high polymer with a molecular weight of 100,000 to 300,000. It is insoluble in most solvents and rubber, hence the name “insoluble sulphur”. The amount of insolubility is usually determined by using carbon disulfide as the solvent. Due to its insolubility, amorphous sulphur is used to prevent “blooming” on uncured rubber surfaces where it is necessary to maintain “building tack”. Insoluble sulphur must not be processed above 210-220°F or it will revert to the rhombic form.

In general, about 1.0 to 3.0 pphr of sulphur is used for most rubber products. Commercially both forms of sulphur are available that have been treated with small amounts of a material (carbon black, magnesium carbonate, etc.) which produces free-flowing, non caking powders. Oil-sulphur mixtures are used occasionally to improve dispersion. Master batches of sulphur with rubbers or rubber-like polymers are also used where processing safety and ease of dispersion are important.

Selenium and tellurium are used in place of sulphur where excellent heat resistance is required. They generally shorten cure time and improve some vulcanisate properties. Selenium is somewhat more active than tellurium.

4.2.7.2 Sulphur-Bearing Chemicals

Accelerators and similar compounds can be used as a source of sulphur for the vulcanisation of natural and synthetic rubbers in recipes using very small amounts of elemental sulphur. Generally in these “low-sulphur” cures, less than 1 pphr of sulphur is used in combination with 3 to 4 pphr of the sulphur donor and in some cases no elemental sulphur is added to the recipe. The compounds used decompose at the vulcanisation temperature and release radicals which combine with the chains to form crosslinks. With these systems, efficient crosslinking occurs as most of the sulphur is combined in crosslinks containing one or two sulphur atoms with little or no cyclic sulphur present. Consequently, this form of vulcanisation produces products which resist aging processes at elevated temperatures much more effectively than those produced with normal curing systems. However, due to the large amounts of sulphur donors used, these systems are more expensive than normal sulphur cures and are only used when necessary. Some typical compounds used in low-sulphur cures are shown in Table 26.

Table 26 Typical Compounds Used For “Low-Sulphur” Vulcanisation

Compound	**Sulphur content (%)**
Tetramethylthiuram disulfide	13.3
Dipentamethylenethiuram hexasulfide	35.0
Dimorpholinyl disulfide	31.4
Dibutylxanthogen disulfide	21.4
Alkylphenol disulfide	23.0

4.2.7.3 Non Sulphur Vulcanisation

Most non sulphur vulcanisation agents, as shown in Table 27, belong to one of three groups: a) metal oxides, b) difunctional compounds, or c) peroxides. Each will be discussed here separately:

a) **Metal Oxides:** Carboxylated nitrile, Butadiene and Styrene-butadiene rubbers may be crosslinked by the reaction of zinc oxide with the carboxylated groups on the polymer chains. This involves the formation of zinc salts by neutralization of the carboxylate groups. Other metal oxides such as Litharge (PbO) and Magnesia are also capable of reacting in the same manner. Polychloroprene (Neoprene) is also vulcanized by reactions with metal oxides; zinc oxide being normally used. Chlorosulphonated polyethylene (Hypalon) is also crosslinked in the same general way. In many of these systems, the metal oxides are used in combinations for the purpose of controlling the vulcanisation rate and absorbing the chlorides formed.

b) **Difunctional compounds:** Certain difunctional compounds form crosslinks with rubbers by reacting to bridge polymer chains into three-dimensional networks. Epoxy resins are used with nitrile; quinone dioximes with butyl; and diamines or dithio compounds with fluororubbers.

c) **Peroxides:** Organic peroxides are used to vulcanize rubbers that are saturated or do not contain any reactive groups capable of forming crosslinks. This type of vulcanisation agent does not enter into the polymer chains but produces radicals which form carbon-to-carbon linkages with adjacent polymer chains.

Table 27 Non Sulphur Vulcanisation Compounds

Compound	Phr usage
Metal Oxides	
Zinc oxide Litharge Magnesia/Pentaerythritol	5 (Neoprene) 25 (Hypalon) 4/3 (Hypalon)
Difunctional Compounds	
Phenolic resins p-Quinonedioxime Hexamethylenediamine carbamate	12 (Butyl) 2 (Butyl) < 1.5 (Fluororubber)
Peroxides	
Dicumyl peroxide (40%) 2,5-bis(t-butylperoxy)-2,5-dimethylhexane	2(Silicone), 5 (Urethane) 2(polyethylene or EPM)

4.2.7.4 Accelerators

The main reason for using accelerators is to aid in controlling the time and/or temperature required for vulcanisation and thus improves the properties of vulcanisate. The reduction in the amount of time required for vulcanisation is generally accomplished by changing the amount and/or types of accelerators (Table 28) used. Some common practices in use by compounders in order to establish suitable recipe charges are as follows:

(a) Single accelerator systems (primary accelerators) which are of sufficient activity to produce satisfactory cures within specified times.

(b) Combinations of two or more accelerators, consisting of the primary accelerator which is used in the largest amount and the secondary accelerator which is used in smaller amounts (10 to 20% of the total) in order to activate and to improve the properties of the vulcanisate. Combinations of this type usually produce a synergistic effect as the final properties are somewhat better than those produced by either accelerator separately.

(c) Delayed action accelerators – these are not affected by processing temperatures (thus providing some protection against scorching) but produce satisfactory cures at ordinary vulcanisation temperatures**.**

Table 28 Chemical classification of Accelerators

Type	Example	Typical use
Aldehyde-amine reaction products	Butyraldehyde-aniline condensation product	Self-curing adhesives
Amines	Hexamethylene tetramine	Delayed action for NR
Guanidines	Diphenyl guanidine	Secondary accelerator
Thioureas	Ethylenethiourea	Fast curing for CR
Thaizoles	2-Mercaptobenzothiazole	Fast curing general purpose broad curing range
	Benzothiazyl disulfide	Safe processing, general purpose moderate cure rate
Thiurams	Tetramethylthiuram Disulfide	Safe, fast curing
Sulfenamides	N-cyclohexyl-2-Benzothiazyl-sulfenamide	Safe processing Delayed action
Dithiocarbamates	Zinc dimethyldithio-carbamate	Fast, low Temperature use
Xanthates	Dibutylxanthogen disulfide	General purpose Low temperature

4.2.7.5 Accelerator Activators

These components are used to increase the vulcanisation rate by activating the accelerator so that it performs more effectively. It is believed that they react in same manner to form intermediate complexes with the accelerators. The complex thus formed is more effective in activating the sulphur present in the mixture, thus increasing the cure rate. Accelerator activators are grouped as follows:

a) Inorganic Compounds: These compounds, (mainly metal oxides) include zinc oxide, hydrated lime, litharge, red lead, white lead, magnesium oxide, alkali carbonates and hydroxides. Zinc oxide is the most common and it is generally used in combination with a fatty acid to form a rubber-soluble soap in the rubber matrix.

b) Organic Acids: Organic acids are normally used in combination with metal oxides. They are generally high molecular weight monobasic acids or mixtures of the following types: stearic, oleic, lauric, palmitic and myristic acids and hydrogenated oils from palm, castor, fish and linseed oils

c) Alkaline substances: Alkaline substances will increase the pH of a rubber compound and in most instances increase the cure rate. As a thumb rule, the majority of recipes, any material which makes the compound more basic will increase the cure rate since acidic materials tend to retard the effect of accelerators. Typical examples of these ingredients include ammonia, amines and salts of amines with weak acids.

5 RUBBER COMPOUNDING TECHNOLOGY

This chapter deals broadly with the art and science of mixing rubber. The goal in mixing is to provide compositions having useful properties and suitable processability with high level of consistency as possible. The terms useful and suitable are determined by the application, for example, what is suitable for a sink stopper might not be suitable for an O-ring. In order to understand the reasons for the techniques and types of machinery employed in mixing, one must have some familiarity with raw materials, their physical forms, their functions in the compound and the behaviour during processing. Several basic categories of ingredients are usually distinguished as follows:

a) Rubber or polymer – bales, chips, pellets or powder

b) Fillers – powder, pellets

   i) Reinforcing – carbon black, silica

   ii) Extending – clay, calcium carbonate, talc

c) Plasticizers and lubricants – fluids, oils, waxes, process oil, ester plasticizers, processing aids, waxes, proprietary blends, stearic acid.

d) Miscellaneous additives – powder, pellets, fluids

   i) Antioxidants, antiozonants

   ii) Colourants

   iii) Release agents

e) Vulcanising agents and accelerators –

   i) Sulphur

   ii) Peroxides

   iii) Special ingredients

The most common types of equipment used in mixing are two-roll mills, internal batch mixers, continuous mixers, extruders or combinations thereof; few of which are explained in subsequent paragraphs.

5.1 Two – Roll Mills

Every mixer must provide two basic functions, both equally important – acceptable dispersion (intensive or dispersive mixing and high uniformity (extensive or distributive mixing). The equipment used most often by the rubber technologist is the two – roll lab mill, a device for preparing small quantities of mixed compound. The rolls and the two roll mill machine are shown in Figure 4 and Figure 5, respectively.

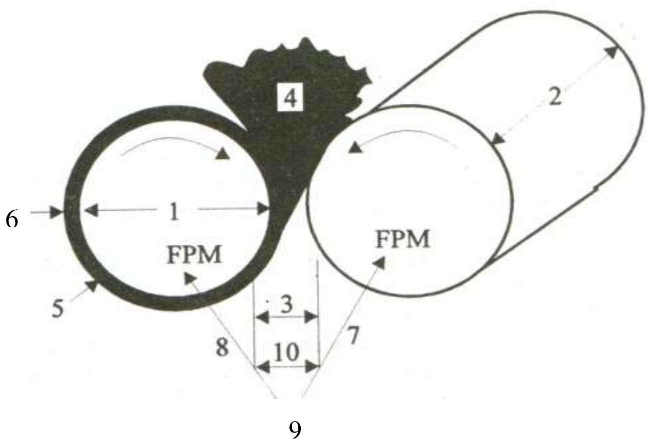


Figure 4 Two-roll mill (numbered quantities are defined in Table 29)

This mixing device is usually set for a ratio of roll surface frictional speed of about 1.25:1. Table 29 illustrates the roll nomenclature.

Table 29 Roll nomenclature (numbers refer to Figure 4)

1	Diameter (D)	Usually same for both rolls
2	Face length (L)	Roll length (mill sizes expressed as D x L)
3	Roll gap	Distance between rolls
4	Sank size	Material sitting above gap
5	Banded roll	Roll which material follows
6	Front roll	Roll on operator's side
7	Slow roll	Roll rotating at slowest speed
8	Fast roll	Roll rotating at fastest speed
9	Friction ratio	Roll speed ratio
10	Separating force	Resultant force exerted by material in roll gap

The rolls are bored to permit cooling or heating the gap between the rolls adjustable within a range related to roll diameter. The mixing procedure is relatively standard. The operator places portions of elastomer on the mill, kneading the sample by multiple passes through the gap, until sufficient reduction in stiffness permits it to wrap and adhere to one roll. The gap is adjusted so that a reservoir of elastomer is always rotating above the nip. This reservoir is called the rolling bank. Rolling is rarely observed when the polymer has only limited elastomeric characteristic at the milling temperature. In such cases the reservoir may flop about or break into discrete sections. This behaviour may often be corrected by a different choice of mill temperature on one roll or both, sometimes merely by using a different nip setting.

Figure 5 Two roll mill

Mills are used more in forming and breakdown applications than in actual mixing except for addition of curatives to pre-mixed master batch. The most common ratio of roll speeds in the past was 1.25:1, with the slower of the two rolls usually on what is most frequently the operator's side (often called the 'front' roll). Recent Investigations have shown that the temperature rise of rubber on a two-roll mill is directly related to the sum of the speeds of two rolls. Therefore, whether the sum reduced by slowing the roll which is faster of two rolls (a change of friction ratio), or by reducing the speed of both rolls the result is a reduction in rubber temperature build – up. Mills built in recent years have had lower total speed ratios closer to 1.1:1 and the fast roll at the front. In addition to improved processing of a broader range of elastomeric compounds, many such mills have also featured drilled rolls, permitting better temperature control and leading to easier compound release.

5.2 Internal Batch Mixers

The Banbury internal mixer was originally manufactured to replace the two-roll mill. The basic design of the machine includes two rotors that operate at a slight speed differential. The rotors are non-interlocking. Mixing or shearing action occurs between the rotors and the sides of the mixer and between the rotors themselves. The mixer is top loaded through and opening large enough to accommodate bales of elastomers (as well as the other ingredients). Pressure is exerted on the batch using a ram which closes the feed opening. Discharge of the batch occurs at the bottom of the mixing chamber. The rotor design is such that material in the chamber is constantly being displaced, corresponding to the cross-blending action of the mill operator cutting the batch on a two – roll mill. The compound is subjected to the shearing action of the rotors against the sides and the action of the rolling bank between the rotors. The internal batch mixer is depicted in Figure 6.

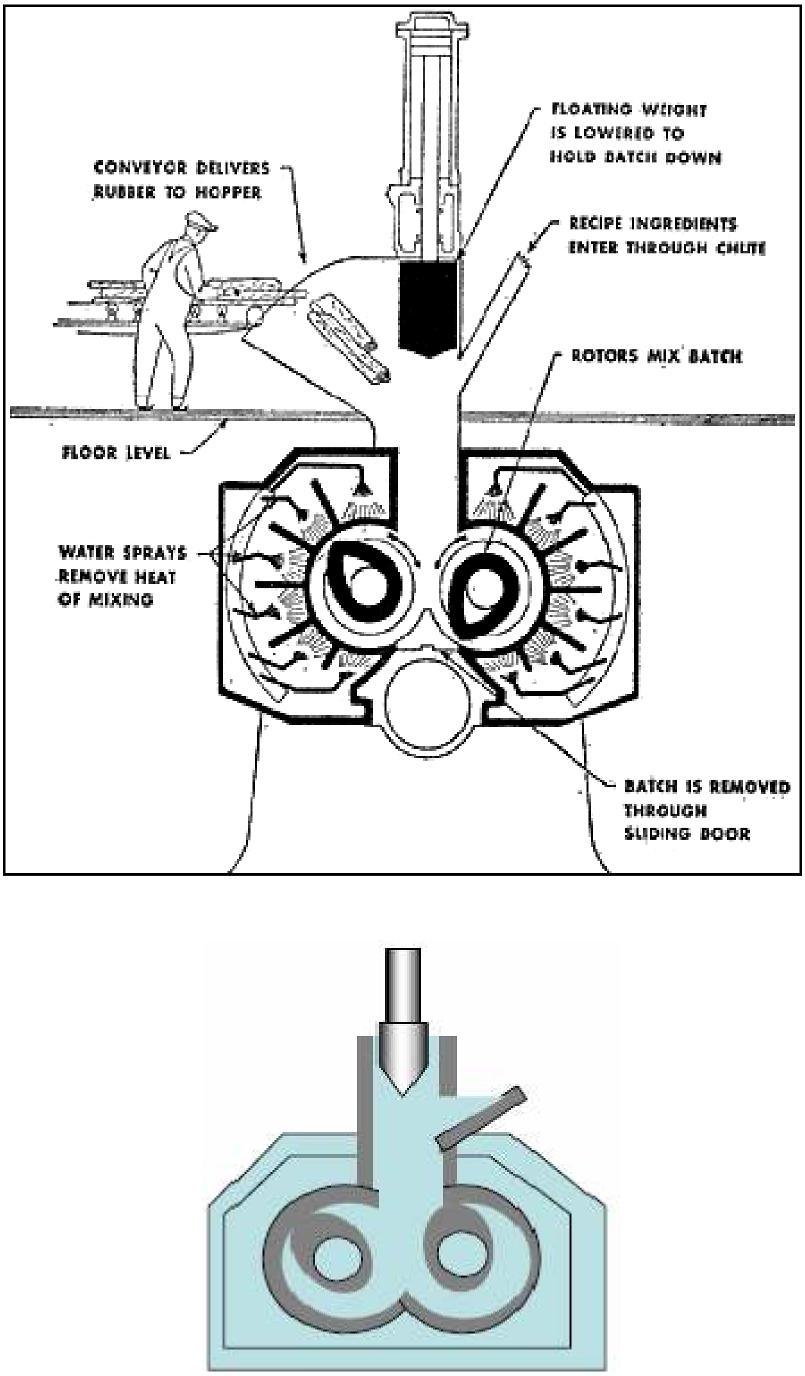


Figure 6 Schematic of Internal batch Mixer

5.3 Continuous Mixers

The Farrel Continuous Mixer (FCM) is shown in Figure 7. It is a counter rotating twin – rotor machine. The FCM generally consists of a sequence of forward pumping screws, a forward pumping mixing rotor section and a backward rotor section. The exit of the machine is not pressurized. The final backward pumping rotor section requires a negative pressure gradient for material to flow through and is thus fully filled. The forward pumping mixing rotor section and prior screw section are starved. Generally, screw sections contain pellets or powder and the first forward pumping rotor section is where the material is masticated and softened. The second backward pumping rotor section is where the rubber or other polymers are mixed.

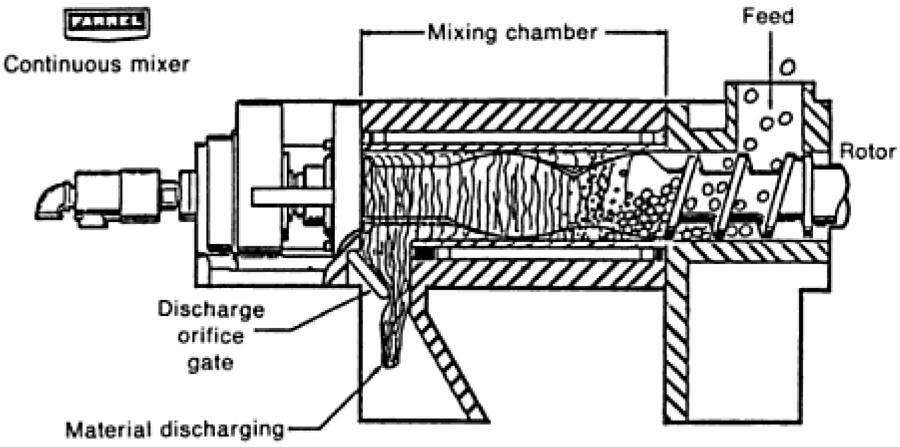


Figure 7 Farrel Continuous Mixer

This mixing would seem a combination of flow over the rotor flights, flow between the rotors and pressure induced flows. An important aspect of the FCM is the short residence times compared to the internal mixer. These are only of order of tens of seconds as contrasted to minutes for the internal mixers.

6 VULCANISATION

After rubber compounds have been properly mixed and shaped into blanks for molding or calendared, extruded, or fabricated into a composite item they must be vulcanized by one of many processes. During vulcanisation, the following changes occur:

i. The long chains of the rubber molecules become crosslinked by reactions with the vulcanisation agent to form three- dimensional structures. This reaction transforms the soft weak plastic like material into a strong elastic product.

ii. The rubber loses its tackiness and becomes insoluble in solvents and is more resistant to deterioration normally caused by heat, light and ageing processes.

6.1 Vulcanisation Systems

i. **Sulphur Vulcanisation**:

Sulphur vulcanization is possible only with unsaturated rubbers. These rubbers crosslink with sulphur and cyclic structures are formed as shown in Figure 8. Generally, x in an efficient accelerated curing system is about 1or 2, with little or no cyclic groups formed. In an inefficient systems x equals up to 8 and many cyclic structures are formed. The total amount of sulphur combined in these networks is usually called the “coefficient of vulcanisation” and is defined as the parts of sulphur combined per one hundred parts of rubber. For most rubbers, one crosslink for about each 200 monomer units in the chain is sufficient to produce a suitable vulcanized product (molecular weight between crosslinks equals 8000 to 10,000).

Figure 8 Sulphur Vulcanisation

The amounts of cyclic sulphur (y) and the excessive sulphur in the crosslinks (x) contribute to the poor ageing properties of the vulcanisates.

ii. **Sulphurless Vulcanisation:**

Vulcanisation effected without elemental sulphur, by the use of thiuram disulphide compounds or with selenium or tellurium, produces products which are more resistant to heat ageing. With thiuram disulphides, efficient crosslinks containing only 1 or 2 sulphur atoms are found and in addition the accelerator fragments act as antioxidants.

iii. **Peroxide Vulcanisation:**

The saturated rubbers cannot be crosslinked by sulphur and accelerators. Organic peroxides are necessary for the vulcanisation of these rubbers. When the peroxides decompose, free radicals are formed on the polymer chains and these chains can then combine to form crosslinks.

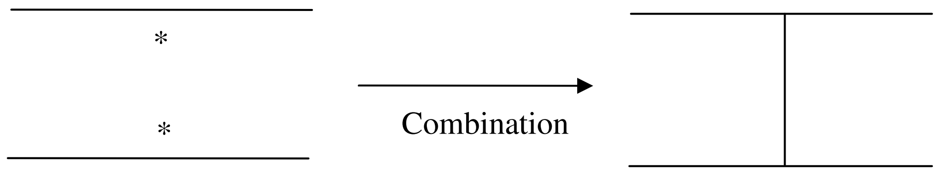


Figure 9 Peroxide vulcanisation

Crosslinks of this type as shown in Figure 9 only involve carbon to carbon bonds and are quite stable. They are also formed by gamma radiation and X-radiation.

iv. **Other Systems:**

Some elastomers can be vulcanized by the use of certain non sulphur bifunctional compounds which form bridge type crosslinks, for example, neoprene with metal oxides or butyl rubber with dinitrosobenzene.

7 TESTING OF ELASTOMERS

In this chapter, a general picture of British and US test procedures is given, with reference to other national procedures containing interesting features. The International Organisation for Standardization Technical Committee ISO/TC 45 on Rubber has since been preparing internationally agreed recommendations on many tests for raw and vulcanised rubbers and more recently for products. These 'ISO Recommendations' are being widely adopted, to be used as the basis for the national standards issued by the standardizing bodies for the member countries of ISO. Hence it will be convenient to refer primarily to the ISO recommendations as the basic documents. Various properties tested on elastomer and their significance is brought out in Table 30.

Table 30 Properties and Significance of Elastomers

S.No.	PROPERTY	SIGNIFICANCE
1	Hardness	1. Pressure Resistance 2. Compressive Load Capability
2	Tear Strength	1. For considerations of removing a molded elastomer part from the production mold 2. For determining the ease of which a tear can start and propagate in application
3	Density	1. Product cost calculations 2. Density is an effective quality procedure to detect variations in the rubber compound composition resulting from changes in ingredient weighing and mixing, among other reasons.
4	Tensile Strength	1. Often used as a criterion of basic compound quality 2. As Quality control parameter relating to Consistency, because the excessive use of inexpensive ingredients to fill out a formulation and lower the cost of the compound will dilute the polymer to the point that tensile strength decreases noticeably. 3. Degradation in these properties may be helpful in predicting the life of elastomer.
5	Elongation	1. Compound having higher elongation will have longer life. 2. The minimum elongation required for service also relates to the type of polymer being used and the stiffness of the compound.
6	Modulus	Mod-100 is a good indication of toughness and resistance to extrusion
7	Compression set	1. For production quality control, indicating the degree of curing. 2. Designers by experience usually relate the compression set value with the life of the component for sealing applications.
8	Abrasion resistance	Resistance of a rubber compound to wearing away when in dynamic contact with an abrasive surface.
9	Chemical Resistance	The rate and the extent of chemical attack of elastomer. It is evaluated by change in dimensions and mechanical properties

10	Low temp properties: Temperature Retraction (TR) test	Measures the retraction of elastomer at various temperature
	Brittleness point	The lowest temperature at which rubber materials do not exhibit brittle failure when impacted under specified conditions
	Gehman Test	Determines the relative stiffness of a material over a temperature range from room temperature down to -150°C
	Compression Set	To study the recovery of original dimensions after removal of a deflecting force at low temperatures to evaluate the seal retention at such temperatures.
11	Heat Ageing	To study the ageing effect caused by the combined effect of heat and oxygen
12	Ozone Resistance Test	To study the capability of Elastomer to resist Ozone

7.1 Hardness:

Hardness test involves the measurement of the depth of penetration of an indenter of specified dimensions under the application of a load either by a dead weight or by a spring. The indentation hardness is a measure of the elastic modulus of the material under conditions of small strain. There are different types of instruments used for measuring the hardness. Some of the most popular ones are the Shore A Durometer (Figure 10), the Rex Gauge, Wallancve Hardness Meter, the International Rubber Hardness Degree Tester (Figure 11) etc.

Reports commonly present data in either Shore A or IRHD units, depending on procedure and equipment, but results are generally similar and within about five points of one another. Other hardness methods, such as Shore M and IRHD-M, often provide more-repeatable results with round O-rings, but they are not comparable to results on flat specimens because part geometry can have a considerable effect on outcomes. For instance, Shore M or IRHD-M data on flat samples are generally similar to those of Shore A and IRHD, while the same tests on otherwise identical small O-rings can differ by 20 points. There is no conversion factor from one method to the other, so engineers cannot legitimately compare Shore M or IRHD-M to Shore A or IRHD results. Hardness is an important property to the compounded rubber since its specification imposes limits upon the type and quantity of certain compounding ingredients like fillers, plasticizers etc. in a particular compound.

In rubber-seal applications, hardness primarily predicts pressure resistance and compressive-load capacity. In a properly designed groove, an "average" 70 durometer material should resist about 1,500 psi (10.3 MPa) fluid pressure without damage. A harder, 90 durometer compound typically handles about 3,000 psi (20.7 MPa) in the same mating hardware. Some extremely hard materials — exceeding 90 durometer — are specifically designed for maximum pressure resistance. But in these cases, hardness does not reliably predict pressure rating.

Figure 10 Durometers (Rubber Hardness Tester)

Figure 11 IRHD Rubber Hardness Tester

Hardness tests are carried out in accordance with the following methods:

ASTM-D-2240 / BS 903 A26 / GOST 263-53 / ISO 7619 : Shore Hardness
ASTM-D-1415 / ISO 48 : IRHD

7.2 Density:

It determines the mass of given rubber compound required to fill a specific mold cavity. Compounds with higher densities require greater weights of the compounds stock to fill a given size mold cavity. Because raw materials are usually purchased by unit weight and molded rubber products are produced from a mold cavity with a fixed volume, knowing the compound density is very important in product cost calculations. Density and specific gravity instruments (Figure 12) are meters used to determine the density and specific gravity of a mixture that may be solid, gas, or liquid. The density range (mass per volume), accuracy and response time characterize most of these instruments. Simultaneous measurements and user interfaces are also important in choosing the proper density and specific gravity instruments. Density digital meters that use the principle of either oscillating tubes or radioactive adsorption to determine density and specific gravity are the most common types of density and specific gravity instruments. An oscillating tube is a hollow glass tube that vibrates at a certain frequency. The vibration frequency changes when the tube is filled with a sample. The higher the mass of the sample, the lower is the vibration frequency. This frequency is measured and converted into density. A built-in thermostat controls the temperature (no water bath required). A thermostat is often necessary since the density of the sample could be changed by temperature variations.

Figure 12 Densitometer

Measuring compound density is an effective quality procedure to detect variations in the rubber compound composition resulting from changes in ingredient weighing and mixing, among other reasons.

Test Methods used to measure density are:

ASTM D-297 Mtd-A / BS 903 A1

7.3 Tear Strength:

Tear strength is defined as the force per unit thickness required to cause a nick out in a rubber when it is stretched, under constant rate, in a direction substantially perpendicular to the plane of the cut. For considerations of removing a molded part from the production mold, or for determining the ease of which a tear can start and propagate in application, tear strength is an important property.

There are different types of test pieces and various methods for applying a tearing force used for conducting the tear tests. The tear test can be performed using the tensile testing machine itself. The tear test specimen types are shown in Figure 13.

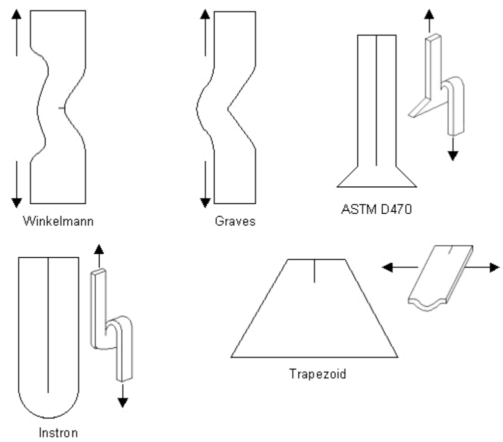


Figure 13 Tear Strength Specimens

Following Test Methods are employed for carrying out density measurement.

- ISO 34, ISO 816
- ASTM D624

7.4 Tensile Properties

The tensile stress-strain properties include tensile strength, elongation at break and tensile modulus that are described elaborate in subsequent paragraphs.

7.4.1 Tensile Strength

Tensile strength is defined as the force per unit area of original cross section of the sample, required to stretch the rubber test piece to its breaking point.

The elastomeric elements are hardly ever used in tension; therefore tensile strength is not a useful property measurement for predicting in-service performance. Further, the tensile strength does not correlate with other important characteristics such as hardness, stress relaxation and fatigue resistance.

However tensile strength is often used as a criterion of basic compound quality and principally used as Quality control parameter relating to Consistency., because the excessive use of inexpensive ingredients to fill out a formulation and lower the cost of the compound will dilute the polymer to the point that tensile strength decreases noticeably.

Degradation in these properties may be helpful in predicting the life of elastomer.

It is often argued that tensile strength is a general index of quality, of wear resistance in particular. This may be true to some extent at the extremes of tensile strength range. For example polyurethane elastomers with their superior tensile strength show in general good abrasion resistance when subjected to rough surfaces and poor lubrication. On the other hand compounds with poor tensile strength such as silicone elastomers, show excessive wear after a short time. However in the middle range (10-20 N/mm^2) where the majority of rubber compounds fall tensile strength has lesser effect on wear resistance.

Test Methods given below is used for Tensile testing of the elastomeric elements

- ASTM-D-412 / BS 903 A2 / GOST 270-64

7.4.2 Elongation

Elongation is defined as the percentage increase in original length (strain) of a specimen produced by a tensile force (stress) applied to the specimen. “Ultimate elongation” is the elongation at the moment the specimen breaks.

Any material that can be reversibly elongated to twice its unstressed length falls within the formal ASTM definition of an elastomer. The upper end of the range for rubber compounds are about 800% and although the lowest end is supposed to be 100%.

It is commonly accepted that the compound having higher elongation will have longer life. The minimum elongation required for service also relates to the type of polymer being used and the stiffness of the compound.

7.4.3 Modulus

Modulus is defined as the force in psi (stress) required in producing a certain elongation (strain). 100% modulus or Mod-100 is a good indication of toughness and resistance to extrusion; *also known as* tensile modulus *or* tensile stress.

Hardness is not a reliable measure of stiffness. Hardness measurements derive from small deformation at the surface, whereas stiffness measurements such as tensile modulus derive from large deformation of the entire mass.

Significance of Tensile tests carried out on an elastomer is explained in following paragraphs.

Significance of Tensile tests:

Tensile tests are useful in determining the resistance of Elastomers to deterioration by heat, liquids, gases, chemicals, ozone, weather and the like. For this purpose the tensile strength, tensile modulus and ultimate elongation are measured before and after an exposure test. The thermal ageing, usually done in an oven at a combination of temperature and time appropriate to the particular type of Elastomers, will result in the definite change in the polymer matrix. Such changes are reflected as alteration in the tensile-test results. Reduction in elongation is typical but tensile strength may increase or decrease. The degree of change of tensile properties resulting from thermal ageing is frequently used as an indicator of compound's ability to withstand ageing and/or lower thermal exposure over long time periods.

As a thumb rule, for a given compound, time required at a given temperature to reduce its tensile strength to about half of its original level represents the functional life of the compound at that temperature.

It is the retention of these physical properties, rather than the absolute values of the tensile stress, elongation or modulus, that play a significant role in determining the effect of thermal or chemical exposure of an elastomer.

Hence Tensile test data are used extensively as quality control parameters and general development tools for the rubber technologists. Various complex process continue to take place in the polymer matrix after moulding is completed which can affect Tensile properties. Therefore normal procedures call for a delay of 8 hours between moulding and testing. A typical Tensile testing Machine as per ASTM D 412 and the dumbbell shaped tensile test specimen are shown in Figure 14 and 15, respectively.

Figure 14 Tensile Testing Machine (ASTM D 412)

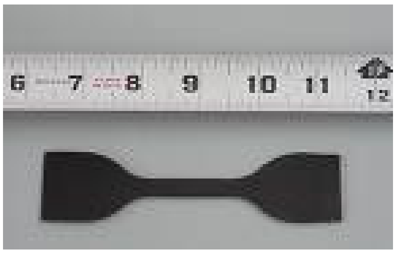


Figure 15 Dumbbell Tensile Test Specimen

7.5 Bulk Modulus/Resiliency

Elastomers are often treated as incompressible materials for analytical convenience. However, in many instances the compressive response of elastomers is very important.

Bulk or Static Modulus: Bulk modulus test assembly is shown in Figure 16. The bulk modulus is a property of a material which defines its resistance to volume change when compressed. It can be expressed as:

K = p / ev

Here p is the hydrostatic pressure, ev is the volumetric strain and K is the bulk modulus. In practice, a positive volumetric strain is defined as a decrease in volume.

Measuring a material's strain response to an applied pressure is a simple test for bulk modulus. The bulk modulus can be expressed as the derivative (slope) of the pressure-strain curve. Relationships between Young's modulus E, the shear modulus G and Poisson's ratio v are related by:

- E = 3 K (1 – 2v)
- E = 2 G (1 + v)

Following Test Methods are used for Bulk or Static Modulus measurement.

- ISO 7743
- ASTM D575

Figure 16 Bulk modulus Test assembly

Rebound Resilience: When a pendulum hammer impacts a rubber specimen from a certain distance or angle, the degree or distance that the pendulum does not return is an indication of the energy lost during the deformation.

Following Test Methods are used for rebound resilience measurement.

- ISO 4662
- ASTM D1054, D2632

7.6 Stress Relaxation / Retained Sealing Force

Elastomers are viscoelastic in nature. When deformed, energy storage is always accompanied by some energy dissipation. The entanglements of the long elastomer chains act as obstructions to the movement of the polymer chains. These obstructions enable the elastomer to store energy—an elastic property. The rearrangements of the polymer chains are dependent on the specific chemical structure, time, temperature and deformation rate. Since elastomers are viscoelastic, the stored energy decreases over time. The decrease of the stored energy (seen as contact sealing force) over time is known as stress relaxation (as per standard BS 903, part A 15; ASTM D1390). In other words, stress relaxation is the change in stress with time when the elastomer is held under constant strain. Common instruments for measuring stress relaxation are Lucas and Wykeham Farrance. The standard methods are:

Method A — compression is applied at test temperature and all force measurements are made at ambient temperature.

Method B — compression and force measurements are made at ambient temperature.

7.7 Compression Set

Elastomer compression set is a measurement of the ratio of elastic to viscous components of an elastomer's response to a given deformation. Longer polymer chains tend to give better "set resistance" because of the improved ability to store energy (elasticity). In traditional compressed seal applications, the rate of "flattening out" is a critical indicator of how long a seal will last. In fact, flattening causes most end-of-life failures in static-seal applications. Unfortunately, mathematical models have not yet linked compression-set values with actual service life, but users can draw general comparisons from applicable data.

Compression set testing (ASTM D395 Method B) involves a simple procedure. A sample of a known thickness is compressed 25% and held in place for a predetermined time at an elevated temperature. After cooling to room temperature, sample thickness is measured "Compression set" is the percent of compression that has been permanently lost obtained using the formula given below. A 0% compression set means that the sample completely returns to its original shape and has lost no thickness; 100% compression set means the sample has permanently deformed to the compressed thickness.

$$\%\,Compression\,Set = \frac{To - Tr}{To - Tc} \times 100$$

where,

T_0 = Initial thickness
T_r = Thickness after retraction
T_c = Compressed thickness

When comparing compression-set details, it is absolutely essential that sample sizes are identical. Resulting values are roughly inversely proportional to the original thickness for samples of identical composition. Geometry plays a role, too. Standard 1/2-in.-thick solid "buttons" of material exhibit slightly better compression set than 0.075-in.-thick discs stacked to the same height. Small O-rings (0.070-in. cross section) of the same material have even higher compression-set values.

With all other test variables equal, materials with lower compression set usually last longer in the field (assuming no other failure mechanisms). However, because no mathematical correlation exists, there is no way to quantify how much longer one material will last compare to another. Experience shows that seals often leak at approximately 80% compression set. However, this rough rule of thumb does not always apply. For products like oil seals, gaskets, engine mounts, bridge bearings etc. the set value should be very low.

The use of elastomer compression set measurements is most beneficial for production quality control, indicating the degree of curing. Usually high loading of reinforcing fillers and under curing of the compound give high set values. Elastomer with high compression set values may require special considerations for gland design and handling. Elastomer compression set is a relatively simple test to perform and as such, may not yield the type of predictive information desired for custom seal applications. Figure 17 shows the schematic view of compression set.

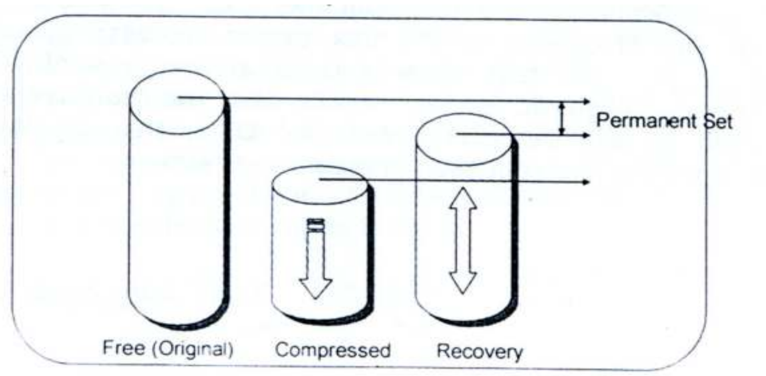


Figure 17 Schematic view of Compression Set

Test Methods for compression set measurement are listed below:

- ASTM-D-395 / BS 903 A6 / GOST 9029-74
- ISO 815 (Ambient & High Temp.)/ISO 1653 (Low Temp.)
- ASTM D 395 (Ambient & High Temp.)/ASTM D1229 (Low Temp.)

7.8 Abrasion Resistance

Progressive wearing of a surface in service by mechanical action such as scraping, rubbing, or erosion is termed as abrasion. Resistance of a rubber compound to wearing when in dynamic contact with an abrasive surface is known as abrasion resistance.

The principle involved in the test is to rub the test sample against standard rough surface, such as the sand paper for a specified time. The loss due to this rubbing is then calculated and expressed as loss in weight. Sand papers or abraders available in the market have been found deficient, in one way or another, as a tool for predicting the service life accurately. But comparative assessments of different compounds can be made with reasonable accurate Abraders that are more popular now days. They are the Du Pont Abrader, Abron Abrader, Good Year Angle Abrader, Pico Abrader and Din abrader as shown in the Figure 18.

Figure 18 Din Abrasion Resistance Tester

Test Methods used are

- ISO 4649, ISO 5470 (Taber)
- ASTM D394 (Du Pont), D1630 (NBS),
- D2228 (Pico), D3389 (Taber)

7.9 Coefficient Of Friction

The coefficient of friction is the ratio of the frictional force between two bodies, parallel to the contact surface, to that of the force normal to the contact surface. Breakaway friction is the threshold friction coefficient as motion begins and running friction is the steady-state friction coefficient as motion continues.

7.10 Volume Resistivity

Volume Resistivity refers to the measure of electrical resistance through a volume of elastomer. This property is useful in predicting conductive or antistatic behavior. It can be measured as per the standard ASTM D991.

7.11 Dielectric Constant (Permittivity)

The ratio of the capacitance of a capacitor filled with the elastomer to that of the same capacitor having only vacuum as the dielectric. It can be measured as per the standard ASTM D150

7.12 Dielectric Strength

The measure of ability of an elastomer to resist the current flow when voltage is applied is stated as Dielectric Strength. It can be measured as per the standard ASTM D149. Failures of elastomeric materials generally occur as a result of:

1. Mechanical stress
2. Effects of chemical moisture degradation
3. Effects of temperature (heat ageing)

The latter two effects generally result in either a loss of mechanical strength (i.e. softening) loss of ductility (i.e. embrittlement), swelling or explosive decompression (i.e. failure from internal expansion of gas upon pressure decompression).

7.13 Chemical Resistance:

Elastomers can be degraded by the action of liquids / gases with which they come in contact during service. Due to absorption / extraction of liquids, the rubber component will either swell or shrink. By swelling, mechanical and functional properties of the component deteriorate. Also dimensions of the component may change. The rate and the extent of chemical attack of Elastomers depend on several factors like:

- Grade of rubber
- The nature of compounding ingredients
- Thickness of elastomeric part and duration of contact
- The temperature
- The chemical composition of the liquid or gas

Test Methods employed are:

- ISO 1817
- ASTM D 471, D1460, D3137

The chemical resistance test is usually carried out by immersing the sample pieces in liquids at specified temperature for a particular interval. The aged sample is tested for its gravimetric change, volumetric change and dimensional change. The usual parameters measured are

- Change in mass
- Change in volume
- Change in hardness
- Change in tensile properties
- Color change of liquid

The most common measure of chemical compatibility for a chemical seal is volume swell. The following formula is used in reporting volume swell measurements. This takes into account dimensional changes in all three dimensions and is more relevant than specific dimensional change readings for a chemical seal.

$$VS\ (\%) = \frac{(\text{Weight in Air} - \text{Wt. in Water})_{final} - (\text{Weight in Air} - \text{Wt. in Water})_{initial}}{(\text{Weight in Air} - \text{Wt. in Water})_{initial}} X\ 100$$

Test Liquids or Standard test oils:

ASTM oils 1 (aniline point: 124ºC)
ASTM oils 2, replaced by IRM 902 (aniline point: 93ºC)
ASTM oils 3, replaced by IRM 903 (aniline point: 70ºC)
ASTM oils 5 (aniline point: 115ºC)
Note: Lower the Aniline point the more severe the swelling action by oil

Standard test liquids are

Fuel A	Iso octane 100
Fuel B	Iso octane 70 Toluene 30
Fuel C	Iso octane 50 Toluene 50
Fuel D	Iso octane 60 Toluene 40
Fuel E	Toluene 100
Fuel F	Diesel fuel
Fuel G	Fuel D 85 ethanol 15
Fuel H	Fuel C 85 ethanol 15
Fuel I	Fuel C 85 methanol 15
Fuel K	Fuel D 15 methanol 15

In order to reduce the test duration chemical resistance tests are usually carried out at a simulated service conditions.

7.14 Measurement of Low Temperature Properties

The low- temperature properties of rubber materials are important in colder climates. High-low temperature limits of various sealing elastomers are illustrated in Enclosure V. The requirements for these properties have since long been included in specifications, especially those of the automotive industry. There are a number of test methods in use; the most common method is the Temperature Retraction Procedure, also known as the TR-test. This test is now also included in the new material specifications that have been developed by the ISO. Another low temperature test is the Gehman test which measures the stiffness (modulus) at a range of temperatures.

A problem with both these methods is that they are both very time consuming to perform however this is eliminated with automated instruments.

7.14.1 Effect of Low Temperatures

A high mobility of the molecular segments in a polymer is the condition for the rubbery state, i.e. high elastic elongation. In a rubber material this is combined with a light cross-linking of the molecular chains. With decreasing temperature the movements of the segments are reduced. At a certain temperature, movements of the molecular segments are completely frozen and the material becomes a stiff, brittle, plastic-like material with low elongation at break. This temperature is called the glass transition temperature, T_g.

7.14.2 The Glass Transition Temperature and Melting Point

The movements of the molecular segments can also be decreased by crystallisation, which means that part of the molecules is arranged in a regular structure. The crystalline, melting point, T_m, which gives the upper temperature limit for this transformation, is higher than the T_g. The crystallisation assumes a certain mobility of the segments and happens therefore with the highest speed at a temperature that lies between T_g and T_m as shown in Figure 19.

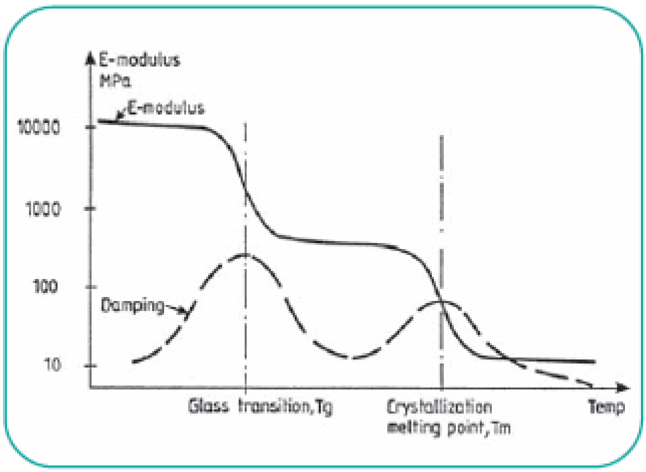


Figure 19 Temperature dependence behaviour of rubber materials

The condition for the rubbery state is consequently a low tendency for crystallisation and a low T_g. If a rubber material is cooled down, the T_g , point will be reached sooner or later and the material becomes stiff and eventually also brittle. This means that the material is no longer useful as a rubber.

Changes in the visco-elastic properties of the rubber occur immediately upon the rubber being cooled down. Changes caused by crystallisation, however, need a certain time to develop and it can take a long time to reach equilibrium.

Most rubber materials have a lowest useful temperature in the region of -25 to -75 °C. Low-temperature properties can also be affected by the composition and especially by type of softener used.

7.15 Review of Low Temperature Test Methods

The Low test methods are described in detail in subsequent paragraphs.

7.15.1 Differential Thermal Analysis (DTA):

Differential Thermal Analysis is a technique for studying the thermal behavior of materials as they undergo physical and chemical changes during heating and cooling. The name is derived from the differential thermocouple arrangement, consisting of two thermocouples wired in opposition. Thermocouple A is placed in a sample of the material to be analyzed. Thermocouple B is placed in an inert reference material, which has been selected so that it will undergo no thermal transformations over the temperature range being studied. When the temperature of the sample equals the temperature of the reference material, the two thermocouples produce identical voltages and the net voltage output is zero. When sample and reference temperatures differ, the resultant net voltage differential reflects the difference in temperature between sample and reference at any point in time. A differential thermocouple is shown in Figure 20.

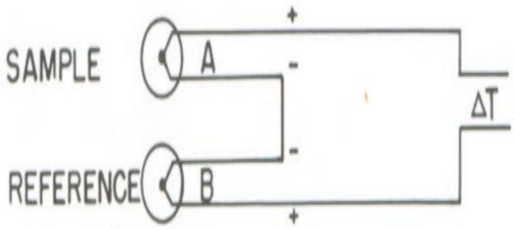


Figure 20 Differential Thermocouple

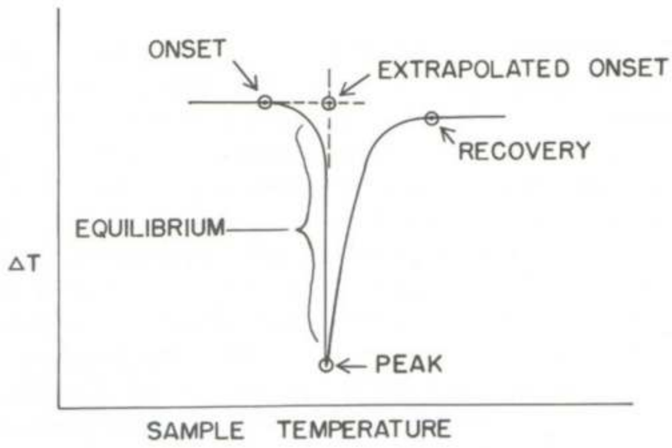


Figure 21 Thermogram for melting of crystals in an elastomer

Physical properties of elastomer which may be studied by DTA include first order transitions (crystallization) and second order transitions (e.g., glass transition). In either case the rubber sample and a material of comparable heat capacity and thermal conductivity, each containing a thermocouple, are cooled rapidly in the DTA chamber to below the suspected transition temperature. The chamber temperature is then raised at a given rate and a plot obtained of ΔT against sample temperature. At transition points the sample will interchange heat with the chamber without a change in its own temperature until the transition is complete, giving a plot of the nature shown in Figure 21 to illustrate crystal melting. In crystal formation the peak would be above the base line while at a second order transition point there would normally be a change in base line to a lower level at the higher temperature.

In addition to its use in locating transition temperatures, DTA has many applications to rubber testing which might be considered chemical rather than physical. These include identification, composition, solvent retention, thermal stability, oxidative stability, polymerization, curing and thermo chemical constants.

7.15.2 Brittleness Point

Brittleness point is the lowest temperature at which rubber materials do not exhibit brittle failure when subjected to impact loading specified condition.

When testing, test pieces in the form of 40 mm x 6 mm strips with and 2 mm thickness are clamped as shown in Figure 22 and then immersed for 5 min in a cold bath. After 5 min they are subjected to a single impact blow, then examined to see if they show any cracks. If they have failed, new test pieces are tested at a temperature 2°C higher. The test is then repeated at higher temperatures until no failure is observed. This temperature is recorded as the temperature limit for brittleness.

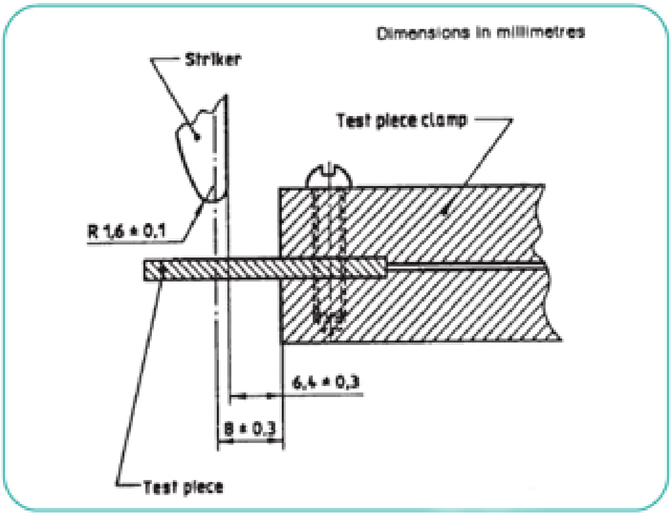


Figure 22 Schematic view of the set up used for determination of brittleness point

Test Methods used are

- ISO 812,
- ASTM D 746

7.15.3 Compression Set at Low Temperature

The principal "rubbery" characteristics which an elastomer must maintain to remain serviceable at low temperatures are a low modulus and freedom from embrittlement. Another property which sometimes becomes important, however, is that of recovering original dimensions after removal of a deflecting force at low temperatures to evaluate the seal retention at such temperatures. This requires a low temperature compression set test of vulcanized elastomers.

The test piece, normally a cylinder, 29 mm in diameter and 12.5 mm length, is compressed to 75% of its original height between two plates equipped with a quick release device. Immediately after compression the jig is placed in a low-temperature cabinet at the test temperature. After 24 or 72 h the test piece is released and the height is measured, normally after 30 minutes. The compression set is then calculated in the normal way to determine remaining deformation.

Test Methods employed are: ISO 815, ASTM D 1229.

7.15.4 Determination of Stiffness Characteristics (Gehman Test): IS0 1432

The Gehman test determines the relative stiffness of a material over a temperature range from -150°C to room temperature. The test can be used both for vulcanised and thermoplastic rubber.

The principle of this test is that a rubber strip of size 40mm x 3mm x 2mm is connected in series with a torsion wire. The combination of torsion wire and the rubber strip is then twisted to a certain angle from one end. The resultant torsional load / force are then decided between the rubber strip and the wire in inverse proportion to their corresponding torsional stiffness.

The stiffness of the material is first determined at room temperature. The bath is then cooled down to the lowest temperature desired. The temperature of the bath is increased by 1 °C/min and the stiffness is measured every 5 minutes. The result can be shown in a graph as the relative modulus against temperature between the stiffness at each temperature and 23 °C. The temperatures at which the relative modulus is 2, 5, 10 and 100 are determined from the curve.

Test Methods used are

ISO 1432, ASTM D 1053

7.15.5 Temperature Retraction Test (TR test)

The principle for this method is to elongate a rubber test piece, lock it and cool it to –70°C in a cold liquid bath, for 10 min. After this time the test piece is released and the temperature is increased by 1°C.

The temperatures at which specified retractions occur are then calculated. The specified retractions are normally, 10%, 30%, 50% and 70% and are called TR10, TR30, TR50 and TR70, respectively. This method is not suitable for TPE-materials, as they can experience high tension set.

Test methods employed are:

IS0 2921, ASTM D 1329-88, BS 903: Part A29

7.15.5.1 TR-tester

The automatic TR-tester consists of a bath for the low temperature liquid and a test rig where the samples are attached. Agitation in the test bath is carried out by a pump system that moves the cold liquid from the bottom to the top of the bath. The heating element used to control the temperature in the bath also covers the bottom of the tank to avoid excessively low temperatures in the bottom as a result of stratification. Bath cooling can either be achieved manually with, for instance dry ice, or automatically with an attached cryogenic bottle with liquid nitrogen.

The test rig is raised by a pneumatic cylinder for ease of use and the retraction of the test pieces is measured by a digital device. Release after the pre-cooling period, the temperature increase and the retraction are all controlled and all data collected by a connected PC-computer, with Windows-based software. Increase in Hardness can be determined as per IS0 3387

This method describes a test based on hardness measurements for determining the progressive stiffening of rubber with time, caused by crystallisation. The method is applicable to both raw and vulcanised rubbers. It is mainly of interest for rubber with a marked crystallisation tendency at temperatures experienced in cold climates such as, for instance, chloroprene and natural rubber.

The test pieces are placed in a cold chamber at the test temperature and the first hardness measurement is done after 15 min conditioning time. The hardness measurements are then repeated after 24 and 168 hr storage. If a curve is to be plotted, measurements can be made at intermediate times.

7.15.6 Determination of Crystallisation at Low Temperatures: ISO 6471

This method describes the determination of the tendency of vulcanised rubber to crystallise and the time dependence of crystallisation, by measurement of the recovery of compressed test pieces. Crystallisation, which occurs more rapidly under high compression, reduces the elastic recovery of the rubber.

The test pieces are first compressed with low deformation and the recovery is determined without crystallisation. The test pieces are then compressed with high deformation and the recovery is determined after crystallisation. Normal holding times are 30 or 60 min, but if the time dependence is to be studied the results after different times are plotted on a graph. From this curve the half-time to crystallisation can be determined.

7.15.7 Dynamic Mechanical Analysis

In a dynamic mechanical instrument the modulus of the test piece is determined continuously, while making a temperature sweep from a low to a high temperature. Often used conditions are a frequency of 1 Hz and a temperature increase of 1°C a minute. The test mode can be tension, compression, bending or shear.

7.16 Heat Ageing

The air oven ageing test (ISO R 188; BS 903, Part A 19; ASTM D573) subjects prepared rubber test-pieces (not complete articles) to slowly circulating and renewed air at constant temperature. Developed from the original Geer oven at 70 ± 1^0 C, is now includes tests at higher temperatures, preferably 100 ± 1°C, 125 ± 1°C, 150 ± 2°C, 175 ± 2°C, 200 ± 2°C or 250 ± 2°C. Some standards warn against using too high a temperature in an attempt to speed up a test intended to simulate prolonged normal-temperature ageing, the higher temperatures (e.g. 100°C or above) being regarded as valid only to simulate high-temperature service.

It has been objected that the tolerances, ± 1°C and ± 2°C permit excessive variation (± 10% and ± 20%), in ageing rate, respectively. So far as these tolerances refer to short-period fluctuations, the objection is not valid, as the average temperature could still be correct. However, the importance of ensuring the correct average is not generally made clear in standard procedures.

As a refinement of the oven test; the cell oven was introduced because, if different rubbers are aged together, they affect each other through the volatile substances evolved (antioxidants, oxidation products, etc.). In the cell oven, each kind of rubber is contained in a separate cylindrical cell, each with its independent air circulation. The cells can conveniently be surrounded by a heating medium (liquid, saturated vapour, aluminum block) kept at the required temperature, so avoiding the trouble encountered, for example, with ovens having electrical units which heat the walls locally, causing radiation that overheats the test-pieces. Variants of the cell oven are 'test tube' ageing (ASTM D865) and a 'tubular' oven with forced ventilation (ASTM D1870).

Test Methods used are

- ISO 188 – "Rubber vulcanised and thermoplastic" (Air Oven and an Oxygen bomb method)
- BS 903: Part A19
- ASTM D 572

7.17 Ozone Resistance Test

Ozone exists in small quantities in the atmosphere but even levels of less than 1 pphm (parts per hundred million) can severely attack non resistant rubbers if they are in the strained condition. Hence ozone attack is often the most important effect of exposure to the atmosphere. The effect of ozone is to produce clearly visible and mechanically very damaging cracking of rubber surface. These tests are usually carried out by exposing the strained test pieces to air containing ozone in an ozone chamber and observing for any crack. The ozone chamber must be constructed of a material such as aluminium which does not decompose ozone.

The air flow rate and the velocity of ozonised air do affect the severity of attack and must be controlled. Most ozone tests are carried out at concentrations in the range of 25 pphm to 200 pphm. Because anti-ozonants and waxes, which are effective, must form a surface bloom, are used to enhance ozone resistance it is usual to condition the test pieces in the strained state before exposure. The usual conditioning period is about 48 and 96 h and the test pieces should be kept in the dark and in an ozone-free atmosphere.

The first criterion for describing a material as ozone resistant is total freedom from cracking. Therefore the higher the threshold strain after a given exposure period, or the higher the limiting threshold strain if this exists, or longer the time before cracks appear at a given strain, better is the ozone resistance.

Test Methods used are

- ISO 1431
- ASTM D 1149

Ozone tests are also carried out in a dynamic mode for those products in service subjected to cyclic strain and because protective wax coating that are easily removed by mechanical contact, cannot withstand cycling there is much logic in using dynamic exposure test. In such tests the test pieces are cycled in tension at 0.5Hz. The exposure and expression of results are generally similar to that of the static standard method but either continuous cycling or a sequence of dynamic cycles and period of static strain is specified.

7.18 Weathering Test

Laboratory tests for ozone resistance do not necessarily correlate well with outdoor weathering tests. The outdoor tests introduce such additional variables as light-catalyzed oxidation, water leaching and changing temperature and ozone concentration. An important feature of the weathering test is the emphasis on control of light intensity. Wavelengths between 2000 and 2500 angstroms are especially critical. Sunlight produces crazing either in stretched or unstretched rubbers, whereas ozone produced cracks. In ASTM D750 the specimens are exposed, either continuously or intermittently, to carbon arc lights and water spray. Ozone may also be present. Exposure effect is judged by tensile tests and visual examination. In ASTM D518 detailed instructions are given for mounting specimens for either laboratory or outdoor weather exposure.

7.19 Adhesion Test

This test is useful in predicting the adhesion property of rubbers to dissimilar material such as fabric, metal etc. ASTM D 429, for testing adhesion of rubber to metal, provides two methods: (1) rubber part assembled between two parallel metal plates and separated by straight pull and (2) rubber part assembled to one metal plate and stripped at 90°. In the first case results are expressed in force per unit area of adhered surfaces and in the second case as force per unit specimen width.

8 AIRWORTHINESS CERTIFICATION OF ELASTOMER

8.1 Elastomers in Aircraft Application

Rubber products are widely used in the aviation/aerospace industry. The ability to withstand extreme temperatures makes rubber parts ideal for use in aircraft and aerospace applications. Various synthetic rubbers can withstand aggressive aerospace fluids, including engine lubrication oils, hydraulic fluids, jet fuels, oxidizers and rocket propellants. Seals fabricated with elastomers like Viton, Hypalon etc. are used regularly in commercial and military aircraft turbine engines, hydraulic actuators, auxiliary power units. The high performance properties of rubber have been well received in many aircraft and missile components and they have proven their superior performance in various applications related to aerospace and aviation such as:

- Auxiliary power units
- Hydraulic actuators
- Aviation, marine and industrial gas turbine engines
- O-rings used in connectors, pumps, valves and oil reservoirs
- Bleed air valves and fittings
- Firewall seals
- T-seals
- Radial lip seals used in pumps
- Cap-seals
- Manifold gaskets
- Coated rubber fabric covers for jet engine exhausts between flights
- Abrasion-resistant solution coating over ignition cable
- Clips for jet engine wiring
- Hose for hot engine lubricants

8.2 Classification of Rubber Components

Depending on the application, a rubber component is classified as critical and non-critical and is explained briefly as follows:

Flight Safety Critical: The Failure of components, systems or items endangers the safety of the aircraft or crew.

Mission Critical: The failure of the components, systems or items result in aborting the aircraft mission.

Non Critical: The failure of components does not endanger the safety of aircraft and crew nor does it result in aborting the mission.

A CEMILAC Guidelines on "Classification of Rubber Seals" stating various service conditions under which the seals are classified is enclosed in ***Enclosure I*** and also an Airworthiness Directive on "Shelf life extension of indigenous rubber seals" which brings out the various classes of rubbers and its shelf life is shown in ***Enclosure II.***

8.3 Airworthiness Approval Procedure of Rubber Compounds

Various Rubber compounds are developed to different specifications. Following points illustrates the Type Approval procedure for Rubber Compounds at RCMA (F &F) division

a. Formulation of rubber compound specification (HM or JSS) based on rationalization of foreign specifications (NFL, MSRR, DTD, MIL or LUCAS).
b. Development of Rubber compound to the above mentioned specification, in-house or through a vendor.
c. Formulation of Test Schedule by design department of main contractor in consultation with RCMA.
d. Carrying out all the tests at approved test house as specified in test schedule.
e. Compilation and submission of test reports in the form of Type Record with recommendations by design department of main contractor and RDAQA approval to RCMA for issue of provisional clearance.
f. Issue of provisional clearance by RCMA.
g. Recommendation for the issue of Type approval by RD, RCMA to CE, CEMILAC after application by the main contractor along with the satisfactory performance feed back by the user

8.4 Airworthiness Approval Procedure for Critical Components

If a component is classified as class I (Flight Safety Critical) or class II (Mission Critical) by the designer, then the component should undergo the following procedure for Airworthiness Approval.

a. All rubber components should be produced from the Type Approved rubber compounds.
b. Study and preparation of Test Schedule (a sample test schedule is illustrated in ***Enclosure III)*** based on the end use of the component in coordination with RCMA.
c. Discussion and clearance of test schedule in the Local Type Certification Committee (LTCC) with Regional Director chairing along with the designers and main contractor.
d. Identification of vendor based on quality approval by RDAQA.
e. Experimental component drawing preparation by vendor/main contractor.
f. Formulation of type test schedule including endurance test (a sample test schedule is illustrated in ***Enclosure IV)*** based on technical specification by main contractor/design approved agency in coordination with user division RCMA.
g. Interaction of all agencies (main contractor, vendor, RCMA, RDAQA) during development and obtain comments on test schedule for finalisation.
h. Development of prototype by vendor or main contractor as indicated in Test schedule
i. Inspection by QC of main contractor and RDAQA for conformity to drawings
j. Three batches should meet the test schedule of the component and tests will be witnessed by RCMA and RDAQA

k. Submission of type record to RCMA duly coordinated by Design/Inspection of main contractor and RDAQA.
l. Issue of provisional clearance after scrutinizing type record by RCMA.
m. Recommendation for type approval by RD, RCMA to CE, CEMILAC with satisfactory performance feedback of the component from the user RCMA division. (The Type Approval is valid for five years from the date of issue of Type approval)
n. Renewal of type approval based on feedback.

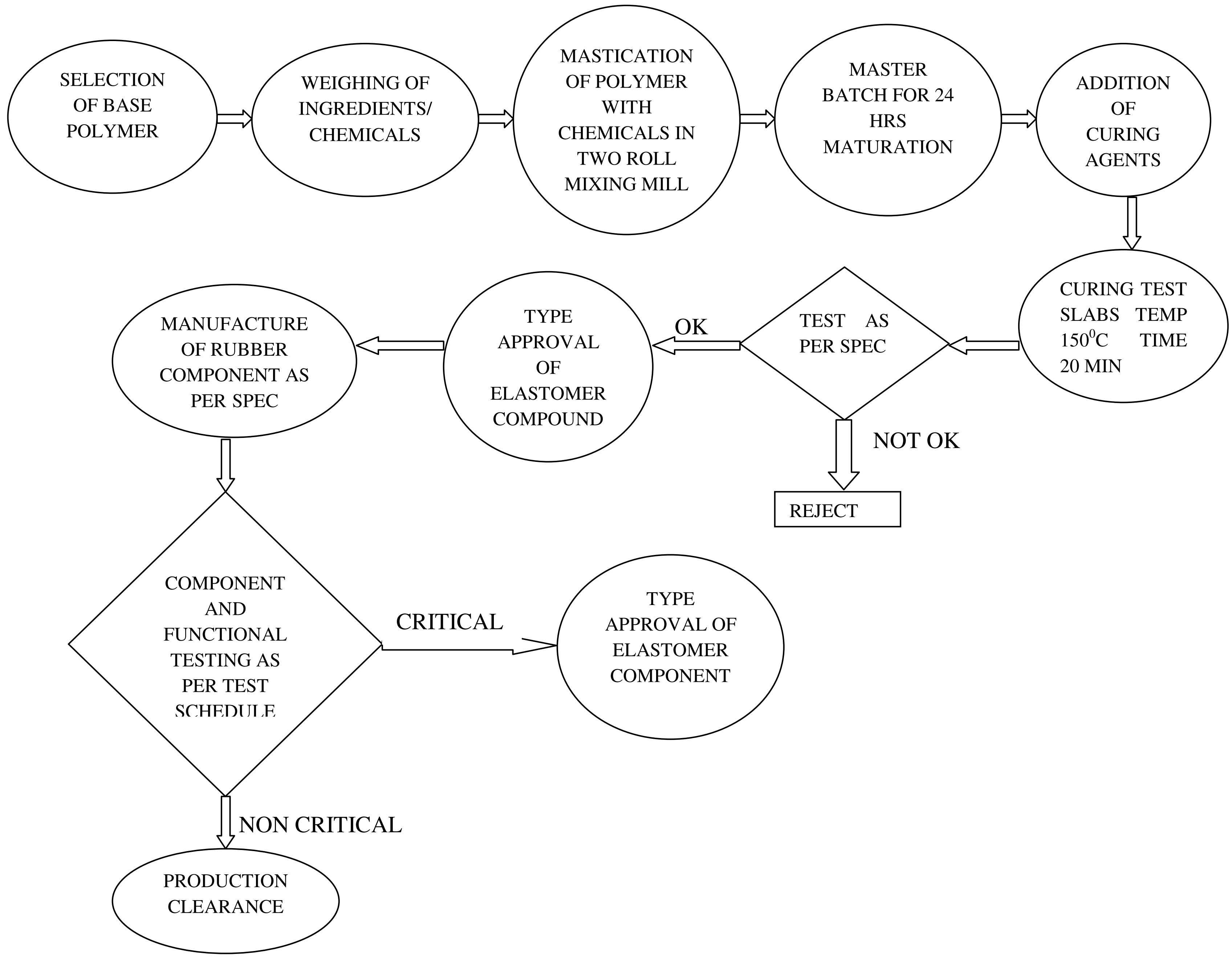
8.5 Airworthiness Approval Procedure for Non Critical Components

If a component is classified as class III (Non Critical), then the component should undergo the following procedure for Airworthiness Approval

a. It should meet all the conditions mentioned for the critical component from a to i
b. One batch should meet the requirement of the specification
c. Same component will be given batch clearance by the RCMA for fitment and functional trials at user division
d. Satisfactory performance feed back will be given by the user RCMA on the successful completion of the functional test at user division
e. The component will be taken up in the LTCC meeting for issue of Production clearance

Flow chart for type approval procedure of elastomer compound & component are illustrated below.

8.6 Flow Chart for Type Approval Procedure of Elastomer Compound & Component



9 TYPE APPROVAL STATUS OF RUBBER COMPOUNDS

Rubber Compounds/Components are the major part of non-metallic materials and there are about 1500 types of elastomer being used in the aviation industry. Most of the rubber compounds are indigenized. Table 31 shows the list of rubber compounds indigenized to different specifications.

Table 31 Type Approval Status of Rubber Compounds

Sl.No.	Nomenclature	Specification	Type approval Ref No.	Approval Valid up to	Supplier
Nitrile Rubber compound					
1	HALTRILE - 01	HM 4880 * DTD 560 Grade C Q/ P * DTD 458A Gr.A Gr.1 * DTD 5509 Grade C	T.A.No. 756	30.06.2009	Foundry & Forge Division
2	HALTRILE - 02	* NFL-17-123A-23 B7	T.A.No. 740	31.12.2009	Foundry & Forge Division
3	HALTRILE - 03	* NFL-17-121A-21 A7	T.A.No. 742	31.12.2009	Foundry & Forge Division
4	HALTRILE - 04	HM 4935 * DTD 560 Grade D Q/ P * DTD 5509 Grade 'D' * NFL-17-120B-20A6 * NFL-17-121A-21A6 * NFL-17-121A-21B6	T.A.No. 675	31.12.2013	Foundry & Forge Division
5	HALTRILE - 05	HM 4885 * NFL-17-121A-21A9 * MSRR 9454 * Lucas Standard 6-18-21	T.A.No. 738	30.06.2009	Foundry & Forge Division
6	HALTRILE - 06	* NFL-17-120B-20B8	T.A.No. 753	31.12.2009	Foundry & Forge Division
7	HALTRILE - 07	HM 4888 * MSRR 9495 * Lucas Standard 6-18-32	T.A.No. 741	31.12.2009	Foundry & Forge Division
8	HALTRILE - 08	* NFL-17-120B-20A5	T.A.No. 759	31.12.2009	Foundry & Forge Division
9	HALTRILE - 09	* NFL-17-120B-20B6	T.A.No. 755	31.12.2009	Foundry & Forge Division
10	HALTRILE - 10	HM 4925 * NFL-17-120B-20 A8 * NFL-17-121A-21 A8	T.A.No. 760	31.12.2009	Foundry & Forge Division
11	HALTRILE - 11	* BACM 573 D Grade - 65	T.A.No. 796	31.12.2012	Foundry & Forge Division
12	HALTRILE - 12	* DTD 560 GR.B Q/P	T.A.No. 1153	30.06.2010	Foundry & Forge Division
13	HALTRILE - 13	* NFL-17-120B-20 A9	T.A.No. 752	31.12.2009	Foundry & Forge Division
14	HALTRILE - 15	* MSRR 9497	T.A.No. 769	31.12.2012	Foundry & Forge

					Division
15	HALTRILE - 16	* NFL-17-121A-21 B4	T.A.No. 743	31.12.2009	Foundry & Forge Division
16	HALTRILE - 17	HM 4889 * MSRR 5008	T.A.No. 754	31.12.2009	Foundry & Forge Division
17	HALTRILE - 19	HM 4886 * NFL-17-120B-20 A7 * NFL-17-120B-20 B7 * NFL-17-124A-24 B7	T.A.No. 739	30.06.2009	Foundry & Forge Division
18	HALTRILE - 20	* DTD 458A GR.B GR.1	T.A.No. 770	31.12.2012	Foundry & Forge Division
19	HALTRILE - 21	* DTD 5509 Grade B	T.A.No. 772	31.12.2012	Foundry & Forge Division
20	HALTRILE - 22	* BACM 573 D Grade - 45	T.A.No. 797	31.12.2012	Foundry & Forge Division
21	HALTRILE - 23	* NFL 17-121A-21B8	T.A.No. 1151	31.12.2010	Foundry & Forge Division
22	EE-20B9	* NFL 17-120B-20B9	T.A.No. 1333	31.12.2012	M/s.Elastomeric Engineers, Salem
23	AE-4934	HM 4934 * Lucas Standard 6-18-59	P.C. No. RCMA(F&F)/314/145/PC-03/08 DT.26.06.2008	25.06.2009	M/s. Aerospace Engineers, Salem
24	EE-21A7	NFL-17-121A-21 A7	T.A.NO. 1275	30.06.2012	M/s Elastomeric Engineers, Salem
25	EE-24 B7	NFL-17-124B-24 B7	T.A.NO. 1274	30.06.2012	M/s Elastomeric Engineers, Salem
26	SI/NR/HM 4888	HM 4888	T.A.NO. 1343	30.06.2013	M/s Sujan Industries, Mumbai
27	Summrub-01-603	DTD 560 Grade “D” Quality “P”	T.A.NO. 1304	31.12.2012	M/s. Summit-Tech (P) Ltd, Bangalore
28	Summrub-01-580	DTD 458A Grade “A1”	T.A.NO. 1305	31.12.2012	M/s. Summit-Tech (P) Ltd, Bangalore
29	Summrub-01-601	DTD 560 Grade “B” Quality “P”	T.A.NO. 1306	31.12.2012	M/s. Summit-Tech (P) Ltd, Bangalore
30	Summrub-01-602	DTD 560 Grade “C” Quality “P”	T.A.NO. 1307	31.12.2012	M/s. Summit-Tech (P) Ltd, Bangalore
31	Summrub-01-600	DTD 560 Grade “A” Quality “P”	T.A.NO. 1308	31.12.2012	M/s. Summit-Tech (P) Ltd, Bangalore.
32	EE -560 Gr.A.Qly.R	DTD 560 Grade .A. Quality “R”	T.A.NO. 1474	31.12.2014	M/s Elastomeric Engineers, Salem
Neoprene Rubber compound					
1	HAL PRENE-01	* NFL-17-131A-31 B5	T.A.NO. 768	31.12.2012	Foundry & Forge Division
2	HAL PRENE-02	HM 4929 * NFL-17-131A-31 B6 * DTD 5514 Grade 'D'	T.A.NO. 1154	30.06.2010	Foundry & Forge Division
3	HAL PRENE-03	* NFL-17-131A-31 B8	T.A.NO. 771	31.12.2012	Foundry & Forge Division
4	HAL PRENE-04	* NFL-17-131A-31 B4	T.A.NO. 1155	30.06.2010	Foundry & Forge Division

5	SI/NEO/HM4930	HM 4930	T.A.NO. 1285	30.06.2012	M/s Sujan Industries, Mumbai
6	EE -31B5	* NFL-17-131A-31B5	T.A.NO. 1277	30.06.2012	M/s Elastomeric Engineers, Salem
7	EE -31B4	* NFL-17-131A-31B4	T.A.NO. 1173	31.12.2010	M/s Elastomeric Engineers, Salem
8	EE -31B6	* NFL-17-131A-31B6	T.A.NO. 1175	31.12.2010	M/s Elastomeric Engineers, Salem
Silicone Rubber compound					
1	Silicone Rubber Compound SH 50±5	HM 4922, ISS.B * NFL-17-150A-50D5 * MSRR 9453	T.A.NO. 787	31.12.2012	M/s.Veekay Rubber products, Mumbai
2	Silicone Rubber Compound SH 60±5	HM 4923 ISS.A * NFL-17-101A-50D6 * BACE-430	T.A.NO. 786	31.12.2012	M/s.Veekay Rubber products, Mumbai
3	Silicone Rubber Compound SH 70±5	HM 4924 ISS.A * NFL-17-101A-50D7 * MSRR 9492	T.A.NO. 785	31.12.2012	M/s.Veekay Rubber products, Mumbai
4	Silicone Rubber Compound EE-4922	HM 4922 ISS.C * NFL-17-150A-50D5 * MSRR 9453 * DTD 5582A GR.50 * DTD 5531A GR.50	T.A.NO.1171	31.12.2010	M/s.Elastomeric Engineers, Salem
5	Silicone Rubber Compound EE-4923	HM 4923 ISS * NFL-17-150A-50D6 * BACE-430 * DTD 5582A GR.60 * DTD 5531A GR.60	T.A.NO. 1167	31.12.2010	M/s.Elastomeric Engineers, Salem
6	EE-50D7	* NFL-17-150A-50D7	T.A.NO. 1441	30.06.2014	M/s.Elastomeric Engineers, Salem
7	EE 5531 Gr 70	DTD 5531 Gr 70	T.A.NO. 1168	31.12.2010	M/s.Elastomeric Engineers, Salem
Fluorosilicone Rubber compound					
1	EE-MIL-R-25988 Gr.60	MILR 25988B Class I Gr. - 60	T.A.NO. 1276	30.06.2012	M/s Elastomeric Engineers, Salem
2	EE 61D6	NFL-17-161B-61D6	T.A.NO. 1170	31.12.2010	M/s Elastomeric Engineers, Salem
3	Fluorosilicone Rubber Compound (Blue) AMS 3326C (50-65)	AMS 3326C	T.A.NO. 1284	30.06.2012	M/s Sujan Industries, Mumbai
Fluorocarbon Rubber compound					
1	Fluorocarbon Rubber Compound SH 75±5	HM 4921 * NFL-17-160A-60C7 * MSRR 9450	T.A.NO. 788	31.12.2012	M/s.Speciality Elastomers, Mumbai
2	Fluorocarbon Rubber Compound	HM 4920 * AMS 7276A * AMS 7280 C	T.A.NO.1169	31.12.2010	M/s.Elastomeric Engineers, Salem

	EE-4920	* DTD 5543 Grade E * DTD 5612 Grade 80			
3	Fluorocarbon Rubber Compound EE-64C8	NFL-17-164B-64C8	T.A NO. 1329	31.12.2012	M/s.Elastomeric Engineers, Salem
4	Fluorocarbon Rubber Compound	HM 4919 * NFL-17-160A-60C9 * MSRR 9451	P.C. No. RCMA(F&F)/PC/164/145/09 Dated 22.01.2009	21.01.2010	M/s.Speciality Elastomers, Mumbai
Natural rubber					
1	HALNAT-01	HM 4931	T.A.NO.1157	30.06.2010	Foundry & Forge Division
Styrene Butadiene Rubber					
1	Elasto SBR-01	MIL R -6855C Class III Grade-60	T.A.NO. 1179	31.12.2010	M/s.Elastomeric Engineers, Salem
Butyl rubber compound					
1	EE – 40B7	NFL-17-101A-40B7	T.A.NO. 1475	31.12.2014	M/s Elastomeric Engineers, Salem

10 LIST OF RUBBER COMPONENTS INDIGENIZED

Table 32 illustrates the details of the parts indigenized to different specifications for western origin aircraft, engines and helicopters. These parts are developed by HAL (F&F) and approved by RCMA (F&F).

Table 32 List of Rubber Components Indigenized

Sl. No.	Project	Part No.	Part Name	Material Spec.
1	Adour	0260101040	SEAL RING	AMS 7280
2	Adour	AS 12801-110	SEALING RING	DTD 5603 Gr E
3	Adour	AS 12801-232	SEALING RING	"
4	Adour	AS 43013-108	SEALING RING	DTD 5613 Gr 80
5	Adour	AS 43013-118	SEALING RING	"
6	Adour	AS 43013-155	SEALING RING	"
7	Adour	AS 43013-161	SEALING RING	"
8	Adour	EU 15573	SEALING RING	MSRR 9450
9	Adour	EU 15681	SEAL RING	"
10	Adour	KB 16204	SEALING RING	MSRR 9454
11	Adour	KB 16206	SEALING RING	"
12	Adour	KB 16208	SEALING RING	"
13	Adour	KB 16212	SEALING RING	"
14	Adour	KB 16216	SEALING RING	"
15	Adour	KB 16220	SEALING RING	MSRR 9454
16	Adour	KB 16222	SEALING RING	"
17	Adour	KB 16224	SEALING RING	MSRR 9454
18	Adour	KB 16227	SEALING RING	"
19	Adour	KB 16233	SEALING RING	MSRR 9454
20	Adour	KB 16235	SEALING RING	"
21	Adour	KB 16250	SEALING RING	"
22	Adour	KB 21004	SEALING RING	MSRR 9450
23	Adour	KB 21006	SEALING RING	"
24	Adour	KB 21008	SEALING RING	"
25	Adour	KB 21010	SEALING RING	"
26	Adour	KB 21012	SEALING RING	"
27	Adour	KB 21018	SEALING RING	MSRR 9450
28	Adour	KB 21020	SEALING RING	"
29	Adour	KB 21023	SEALING RING	"
30	Adour	KB 21024	SEALING RING	"
31	Adour	KB 21027	SEALING RING	"
32	Adour	KB 21029	SEALING RING	"
33	Adour	KB 21031	SEALING RING	"
34	Adour	KB 21033	SEALING RING	"
35	Adour	KB 21034	SEALING RING	"
36	Adour	KB 21042	SEALING RING	"

37	Adour	KB 21071	SEALING RING	"
38	Adour	KB 21073	SEALING RING	"
39	Adour	KB 21076	SEALING RING	"
40	Adour	KB 21078	SEALING RING	"
41	Adour	KB 21082	SEALING RING	"
42	Adour	KB 21096	SEALING RING	"
43	Adour	KB 21104	SEALING RING	"
44	Adour	KB 21304	SEAL RING	"
45	Adour	KB 21305	SEAL RING	"
46	Adour	KB 21307	SEAL RING	"
47	Adour	KB 21308	SEAL RING	"
48	Adour	KB 21309	SEAL RING	"
49	Adour	KB 21310	SEAL RING	"
50	Adour	KB 21316	SEAL RING	"
51	Adour	KB 21318	SEAL RING	"
52	Adour	KB 21320	SEAL RING	"
53	Adour	KB 21324	SEAL RING	MSRR 9450
54	Adour	KB 21328	SEAL RING	"
55	Adour	KB 21329	SEAL RING	"
56	Adour	KB 21345	SEAL RING	"
57	Adour	KB 21370	SEAL RING	"
58	Adour	KB 21383	SEAL RING	"
59	Adour	KB 21624	SEALING RING	"
60	Adour	KB 21626	SEALING RING	"
61	Adour	KB 21630	SEALING RING	"
62	Adour	KB 25110	SEALING RING	"
63	Adour	KB 25112	SEALING RING	"
64	Adour	KB 25232	SEALING RING	"
65	Adour	RU27682	SEAL RING	"
66	Adour	YU11748	SEALING RING	"
67	Adour	AS 43013-116/H	SEALING RING	DTD 5613 GR. 80
68	Adour	AX 56265/H	SEAL RING	MSRR 9453
69	Adour	KB 16210/H	SEALING RING	MSRR 9454
70	Adour	48 X 2 - 61D6/H	`O'RING	NFL-17-161B-61D6
71	Adour	KB 21016/H	SEAL RING	MSRR 9450
72	Artouste	0000220160	SEALING RING	21A7
73	Artouste	0111720140	SEALING RING	"
74	Artouste	9560110050	SEALING RING	"
75	Artouste	9560126790	SEALING RING	64C8
76	Artouste	9560144500-8	SEALING RING	60C7
77	Artouste	9567148502-6	SEALING RING	"
78	Artouste	9681501401	`O'RING	"
79	Artouste	9681504001	`O'RING	"
80	Artouste	9681800921	`O'RING	"
81	Artouste	9681900262	`O'RING	"

82	Artouste	9681900891	`O'RING	"
83	Artouste	9681502001	`O'RING	"
84	Artouste	9682000851	`O'RING	60C7
85	Artouste	9682001451	`O'RING	21A7
86	Artouste	9682002701	`O'RING	"
87	Artouste	9682004001	`O'RING	"
88	Artouste	9682007101	`O'RING	"
89	Artouste	9682009001	SEALING RING	"
90	Artouste	9682201141	`O'RING	64C8
91	Artouste	9682401331	`O'RING	21A7
92	Artouste	9682500851	`O'RING	"
93	Artouste	9682500911	`O'RING	"
94	Artouste	9682501251	`O'RING	"
95	Artouste	9682522001	`O'RING	"
96	Artouste	9682700892	`O'RING	60C7
97	Artouste	9682701362	`O'RING	"
98	Artouste	9682701512	`O'RING	"
99	Artouste	9682701513	SEALING RING	64C8
100	Artouste	9683008301	`O'RING	21A7
101	Artouste	9794055221	`O'RING	"
102	Artouste	9794065221	`O'RING	"
103	Artouste	9794075221	`O'RING	"
104	Artouste	9794095221	`O'RING	"
105	Artouste	S7275/H	`O'RING	21A9
106	Artouste	H 0044130260	RUBBER DISC	"
107	Artouste	H10001132	`O'RING	"
108	Artouste	H10001133	RUBBER SEAL	"
109	Artouste	9682701211/H	`O'RING	"
110	Artouste	0044130020/H	VALVE SEAT	"
111	Artouste	9681900341/H	`O'RING	"
112	Artouste	9488008/H	SEALING RING	20A9
113	Artouste	9681003401/H	SEALING RING	21A7
114	Artouste	9681900722/H	`O'RING	"
115	Artouste	9207478000/H	GASKET	20A6
116	Artouste	9207477000/H	GASKET	"
117	Dart	77064190	SEALING RING	6-18-32
118	Dart	AU 9133	SEALING RING	MSRR 9450
119	Dart	BR 1683	SEALING RING	MSRR 9495
120	Dart	BR 4120	RING SEALING	"
121	Dart	BR 37224	SEALING RING	MSRR 9450
122	Dart	BR 40503	RING SEALING	"
123	Dart	GTS 56-1	COMBINATION WASHER	6-18-32
124	Dart	GTS 56-2	COMBINATION WASHER	"
125	Dart	GTS 56-3	COMBINATION WASHER	"
126	Dart	GTS 100-3	SEALING RING	"

127	Dart	GTS 240-2	SEALING RING	"
128	Dart	GTS 240-3	SEALING RING	"
129	Dart	GTS 240-4	SEALING RING	"
130	Dart	GTS 240-5	SEALING RING	"
131	Dart	GTS 240-6	SEALING RING	"
132	Dart	GTS 240-7	SEALING RING	"
133	Dart	GTS 240-8	SEALING RING	"
134	Dart	GTS 240-9	SEALING RING	"
135	Dart	GTS 240-10	SEALING RING	"
136	Dart	GTS 240-13	SEALING RING	"
137	Dart	GTS 240-14	SEALING RING	"
138	Dart	GTS 240-20	SEALING RING	"
139	Dart	GTS 240-23	SEALING RING	"
140	Dart	KB 16003	RING SEALING	MSRR 9495
141	Dart	KB 16005	RING SEALING	"
142	Dart	KB 16008	RING SEALING	"
143	Dart	KB 16012	RING SEALING	"
144	Dart	KB 16016	RING SEALING	MSRR 9495
145	Dart	KB 16024	RING SEALING	"
146	Dart	KB 16026	RING SEALING	"
147	Dart	KB 16028	RING SEALING	"
148	Dart	KB 16032	RING SEALING	"
149	Dart	KB 16042	RING SEALING	"
150	Dart	KB 16048	RING SEALING	"
151	Dart	KB 16501	RING SEALING	"
152	Dart	KB 16502	RING SEALING	"
153	Dart	KB 16503	RING SEALING	"
154	Dart	KB 16504	RING SEALING	"
155	Dart	KB 16505	RING SEALING	"
156	Dart	KB 16506	RING SEALING	"
157	Dart	KB 16507	RING SEALING	"
158	Dart	KB 16508	RING SEALING	"
159	Dart	KB 16509	RING SEALING	"
160	Dart	KB 16510	RING SEALING	"
161	Dart	KB 16511	RING SEALING	"
162	Dart	KB 16512	RING SEALING	"
163	Dart	KB 16513	RING SEALING	"
164	Dart	KB 16517	RING SEALING	"
165	Dart	KB 16518	RING SEALING	"
166	Dart	KB 16520	RING SEALING	MSRR 9495
167	Dart	KB 16526	RING SEALING	"
168	Dart	KB 16540	RING SEALING	"
169	Dart	KB 16551	RING SEALING	MSRR 9495
170	Dart	KB 21002	SEAL RING	MSRR 9450
171	Dart	KB 21012	SEAL RING	"

172	Dart	KB 21018	SEAL RING	"
173	Dart	KB 21026	SEAL RING	"
174	Dart	KB 21302	SEALING RING	"
175	Dart	KB 21303	SEALING RING	"
176	Dart	KB 21304	SEALING RING	"
177	Dart	KB 21305	SEALING RING	"
178	Dart	KB 21306	SEALING RING	"
179	Dart	KB 21307	SEALING RING	"
180	Dart	KB 21309	SEALING RING	"
181	Dart	KB 21310	SEALING RING	"
182	Dart	KB 21312	SEALING RING	"
183	Dart	KB 21313	SEALING RING	"
184	Dart	KB 21321	SEALING RING	"
185	Dart	KB 21327	SEALING RING	"
186	Dart	KB 21337	SEALING RING	"
187	Dart	KB 21341	SEALING RING	"
188	Dart	KB 21357	SEALING RING	"
189	Dart	KB 21368	SEALING RING	"
190	Dart	KB 21606	SEALING RING	"
191	Dart	KB 21610	SEALING RING	"
192	Dart	KB 21614	SEALING RING	"
193	Dart	KB 21618	SEALING RING	"
194	Dart	RK 12980	RING SEALING	DTD 560 Gr-B Q/P
195	Dart	RK 21402	RING SEALING	MSRR 9495
196	Dart	RK 21873	RING SEALING	"
197	Dart	RK 21874	RING SEALING	"
198	Dart	RK 21875	RING SEALING	"
199	Dart	RK 21876	RING SEALING	"
200	Dart	RK 21879	WASHER RUBBER	"
201	Dart	RK 21880	WASHER	"
202	Dart	RK 21882	SEALING RING	"
203	Dart	RK 21883	RING SEALING	"
204	Dart	RK 21884	RING SEALING	"
205	Dart	RK 22197	RING SEALING	"
206	Dart	RK 22198	RING SEALING	"
207	Dart	RK 22669	RING SEALING	"
208	Dart	RK 35239	SEALING RING	MSRR 9450
209	Dart	RK 35240	SEALING RING	"
210	Dart	RK 39935	SEALING RING	"
211	Dart	RK 43136	SEAL	MSRR 9454
212	Dart	Y 77065569	SEALING RING	6-18-21
213	Dart	Z 17101-107	COVER JOINT RING	6-18-32
214	Dart	Z 17101-44	QUILL SEALING RING	"
215	Dart	Z 7061-231	SEALING RING	"
216	Dart	Z 7061-232	SEALING RING	"

217	Dart	Z 7061-233	SEALING RING	"
218	Dart	Z 7061-613	SEALING RING	"
219	Dart	Z 7061-849	SEAL	6-18-21
220	Dart	Z 7083-431	SEAL	"
221	Dart	RK 24737	BUSH	MSRR 9497
222	Dart	RK 25533	BUSH	"
223	Dart	RK 25537	WASHER	"
224	Dart	RK 33357	RING SEALING	MSRR 9450
225	Dart	Z 7083 / 50 /H	AD.SCREW WASHER	6-18-21
226	Dart	RK 22670/H	RING SEALING	MSRR 9454
227	Dart	KB 16524/H	SEALING RING	MSRR 9495
228	Dart	RK 25535/H	WASHER	MSRR 9497
229	Dart	Z 17106-89/H	SEALING RING	6-18-32
230	Dart	Z 7061202/H	SEAL	6-18-32
231	Dart	Z 7061156/H	SEAL	6-18-32
232	Dart	Z 7061191.X/H	SEAL	6-18-32
233	Dart	RK 21878/H	RING SEALING	MSRR 9495
234	Dart	RK 25532/H	BUSH	MSRR 9497
235	Dart	RK 25536/H	WASHER	"
236	Dart	RK 22849/H	BUSH	MSRR 9495
237	Dart	RK 22998/H	BUSH	MSRR 9497
238	Dart	RK 50303	SEALING RING	MSRR 9450
239	Dart	CU 60405	RING SEALING	"
240	Dart	RK 37596/H	SEAL	MSRR 9495
241	Dart	RK 43135/H	SEAL	"
242	Dart	7083-276/H	RUBBER WASHER	6-18-32
243	Dart	COM 6287/H	SEALING RING	MSRR 9453
244	Dart	COM 6308/H	SEALING RING	"
245	Dart	COM 6285/H	SEALING RING	"
246	Dart	30781118478/H	RING SEALING	DTD 5509 GR. B
247	Dart	KB 21016/H	SEALING RING	MSRR 9450
248	Dart	Z 17101-69/P/H	RING SEALING	6-18-32
249	Dart	Y7010357/H	SEAL	6-18-21
250	Garrett	S 9413-006	PACKING	AMS 7276A
251	Garrett	S 9413-007	PACKING	"
252	Garrett	S 9413-010	PACKING	"
253	Garrett	S 9413-011	PACKING	"
254	Garrett	S 9413-012	PACKING	"
255	Garrett	S 9413-013	PACKING	"
256	Garrett	S 9413-014	PACKING	"
257	Garrett	S 9413-016	PACKING	"
258	Garrett	S 9413-017	PACKING	"
259	Garrett	S 9413-018	PACKING	"
260	Garrett	S 9413-019	PACKING	"
261	Garrett	S 9413-021	PACKING	"

262	Garrett	S 9413-022	PACKING	"
263	Garrett	S 9413-032	PACKING	"
264	Garrett	S 9413-033	PACKING	"
265	Garrett	S 9413-034	PACKING	"
266	Garrett	S 9413-036	PACKING	"
267	Garrett	S 9413-037	PACKING	"
268	Garrett	S 9413-110	PACKING	"
269	Garrett	S 9413-111	PACKING	"
270	Garrett	S 9413-112	PACKING	"
271	Garrett	S 9413-114	PACKING	"
272	Garrett	S 9413-115	PACKING	"
273	Garrett	S 9413-117	PACKING	"
274	Garrett	S 9413-119	PACKING	"
275	Garrett	S 9413-153	PACKING	"
276	Garrett	S 9413-165	PACKING	"
277	Garrett	S 9413-227	PACKING	"
278	Garrett	S 9413-231	PACKING	"
279	Garrett	S 9413-526	PACKING	"
280	Garrett	S 9413-529	PACKING	"
281	Garrett	S 9413-552	PACKING	"
282	Garrett	S 9413-555	PACKING	"
283	Garrett	S 9413-560	PACKING	"
284	Garrett	S 9413-656	PACKING	"
285	Gnome	AS 43013-008	RING SEALING	DTD 5613 Gr 80
286	Gnome	AS 43013-010	RING SEALING	"
287	Gnome	AS 43013-012	RING SEALING	"
288	Gnome	AS 43013-013	RING SEALING	"
289	Gnome	AS 43013-014	RING SEALING	"
290	Gnome	AS 43013-015	RING SEALING	"
291	Gnome	AS 43013-016	RING SEALING	"
292	Gnome	AS 43013-017	RING SEALING	"
293	Gnome	AS 43013-018	RING SEALING	"
294	Gnome	AS 43013-021	RING SEALING	"
295	Gnome	AS 43013-024	RING SEALING	"
296	Gnome	AS 43013-026	RING SEALING	"
297	Gnome	AS 43013-028	RING SEALING	"
298	Gnome	AS 43013-031	RING SEALING	"
299	Gnome	AS 43013-041	RING SEALING	"
300	Gnome	AS 43013-111	RING SEALING	"
301	Gnome	AS 43013-112	RING SEALING	"
302	Gnome	AS 43013-116	RING SEALING	"
303	Gnome	AS 43013-128	RING SEALING	"
304	Gnome	AS 43013-140	RING SEALING	"
305	Gnome	AS 43013-212	RING SEALING	"
306	Gnome	AS 43013-213	RING SEALING	"

307	Gnome	AS 43013-224	RING SEALING	"
308	Gnome	AS 43013-244	RING SEALING	"
309	Gnome	AS 43013-246	RING SEALING	"
310	Gnome	AS 43013-247	RING SEALING	"
311	Gnome	AS 12801-232	SEALING RING	DTD 5603 Gr E
312	Gnome	GTS 56-1/H	COMBINATION WASHER	6-18-32
313	Gnome	GTS 240-2/H	SEALING RING	"
314	Gnome	GTS 240-3/H	SEALING RING	"
315	Gnome	GTS 240-4/H	SEALING RING	"
316	Gnome	GTS 240-5/H	SEALING RING	"
317	Gnome	GTS 240-6/H	SEALING RING	"
318	Gnome	GTS 240-7/H	SEALING RING	"
319	Gnome	GTS 240-8/H	SEALING RING	"
320	Gnome	GTS 240-10/H	SEALING RING	"
321	Gnome	GTS 240-14/H	SEALING RING	"
322	Gnome	Z 7084-21/H	SEALING RING	6-18-21
323	Gnome	GTS 242-3/H	SEALING RING	"
324	Gnome	100-845-1113/H	SEALING RING	MSRR 5008
325	Gnome	GTS 242-5/H	SEALING RING	6-18-21
326	Gnome	GTS 242-17/H	SEALING RING	"
327	Gnome	GTS 245-1/H	SEALING RING	"
328	Gnome	GTS 245-2/H	SEALING RING	"
329	Gnome	GTS 245-3/H	SEALING RING	"
330	Gnome	GTS 245-4/H	SEALING RING	"
331	Gnome	GTS 245-5/H	SEALING RING	"
332	Gnome	GTS 245-6/H	SEALING RING	"
333	Gnome	GTS 245-6A/H	SEALING RING	"
334	Gnome	GTS 245-7/H	SEALING RING	"
335	Gnome	GTS 245-07/H	SEALING RING	"
336	Gnome	GTS 245-9	SEALING RING	"
337	Gnome	GTS 245-12/H	SEALING RING	"
338	Gnome	GTS 245-13/H	SEALING RING	"
339	Gnome	GTS 245-14A/H	SEALING RING	"
340	Gnome	26121-6122/H (or WS 12440-2/H)	SEALING RING	MSRR 5008
341	Gnome	26121-6149/H (or 90261/H)	O-RING	"
342	Gnome	26121-6247/H (or 90300/H)	SEALING RING	MSRR 9495
343	Gnome	GTS 345-215	SEALING RING	DTD 5613 GR. 80
344	Gnome	GTS 345-242	SEALING RING	"
345	Gnome	77600094	SEALING RING	21A6
346	Gnome	77600088	SEALING RING	"
347	Gnome	Z17101-69/P/H	RING SEALING	6-18-32
348	Orpheus	B 206848	BLADE, COMPRESSOR ENTRY GUIDE UNIT	21A8
349	Orpheus	GTS 240-1	RUBBER SEAL	6-18-32

350	Orpheus	GTS 240-3	RUBBER SEAL	"
351	Orpheus	GTS 240-4	RUBBER SEAL	"
352	Orpheus	GTS 240-5	RUBBER SEAL	"
353	Orpheus	GTS 240-6	RUBBER SEAL	"
354	Orpheus	GTS 240-7	RUBBER SEAL	"
355	Orpheus	GTS 240-8	RUBBER SEAL	"
356	Orpheus	GTS 240-11	RUBBER SEAL	"
357	Orpheus	GTS 240-13	RUBBER SEAL	"
358	Orpheus	GTS 240-14	RUBBER SEAL	"
359	Orpheus	GTS 240-23	RUBBER SEAL	"
360	Orpheus	GTS 242-2	SEALING RING	6-18-21
361	Orpheus	GTS 242-3	SEALING RING	"
362	Orpheus	GTS 242-4	SEALING RING	"
363	Orpheus	GTS 242-6	SEALING RING	"
364	Orpheus	GTS 242-7	SEALING RING	"
365	Orpheus	GTS 242-9	SEALING RING	"
366	Orpheus	GTS 242-10	SEALING RING	"
367	Orpheus	GTS 242-13	SEALING RING	"
368	Orpheus	GTS 242-14	SEALING RING	"
369	Orpheus	GTS 242-15	SEALING RING	"
370	Orpheus	GTS 242-19	SEALING RING	"
371	Orpheus	SH 68-A3	`O'SEAL	MSRR 5008
372	Orpheus	SH 68-A5	`O'SEAL	"
373	Orpheus	SH 68-A6	`O'SEAL	"
374	Orpheus	SH 68-A7	`O'SEAL	"
375	Orpheus	SH 68 B1	`O'SEAL	MSRR 5008
376	Orpheus	SH 68 B2	`O'SEAL	"
377	Orpheus	SH 68 B3	`O'SEAL	"
378	Orpheus	SH 68 B4	`O'SEAL	"
379	Orpheus	SH 68 B5	`O'SEAL	"
380	Orpheus	SH 68 B6	`O'SEAL	"
381	Orpheus	SH 68-C1	`O'SEAL	"
382	Orpheus	SH 68-C2	`O'SEAL	"
383	Orpheus	SH 68-C5	`O'SEAL	"
384	Orpheus	SH 68-C6	`O'SEAL	"
385	Orpheus	SH 68-C8	`O'SEAL	"
386	Orpheus	SH 68-C12	`O'SEAL	"
387	Orpheus	SH 68-C13	`O'SEAL	"
388	Orpheus	SH 68-C14	`O'SEAL	"
389	Orpheus	SH 68-C16	`O'SEAL	"
390	Orpheus	SH 68-C19	`O'SEAL	"
391	Orpheus	SH 68-C22	`O'SEAL	"
392	Orpheus	SH 68-C29	`O'SEAL	"
393	Orpheus	SH 68-E7	`O'SEAL	"
394	Orpheus	SH 70-A4	`O'SEAL	BACE430

395	Orpheus	SH 70-A6	`O'SEAL	"
396	Orpheus	SH 70-C4	`O'SEAL	"
397	Orpheus	SH 70-C6	`O'SEAL	"
398	Orpheus	Y 7100-400	SEALING RING	6-18-21
399	Orpheus	Z 17097-65	RUBBER SEAL	6-18-32
400	Orpheus	Z 7084-21	SEALING RING	6-18-21
401	Orpheus	Z 7482011.X	GROMMET SEAL	6-18-32
402	Orpheus	AS 43013-118	RING SEALING	DTD 5613 GR 80
403	Orpheus	GTS 240-17/H	SEALING RING	6-18-32
404	Orpheus	GTS 240-18/H	SEALING RING	"
405	Orpheus	Z 7078-391/H	SEAL	"
406	Orpheus	GTS 242-5/H	SEALING RING	6-18-21
407	Orpheus	GTS 108-2/H	SEALING RING	"
408	Orpheus	GTS 100-3/H	SEALING RING	6-18-32
409	Orpheus	GTS 242-17/H	SEALING RING	6-18-21
410	Orpheus	P8577/H	RUBBER SEAL	DTD 5509 GR. C
411	Orpheus	SH 68-C11/H	`O'SEAL	MSRR 5008
412	Orpheus	Y 7010357/H	SEAL	6-18-21
413	ALH	2-73017/H	CAP	31B5
414	ALH	SK/ALH/DH-SP-0446/H	SEAL-RESCUE HOIST	DTD 458AGR A GR I
415	ALH	SK/ALH/DH-SP-0490/H	`O'RING	23B7
416	ALH	201P 242H 1001 201/H	`O'RING	"
417	ALH	201P 252H 4100 205/H	RUBBER PAD (TOP)	31B6
418	ALH	201P 252H 4100 206/H	RUBBER PAD (BOT)	"
419	ALH	201P 281H 1100 207/H	STATIC`O'SEAL	21B6
420	ALH	201P 281H 1200 205/H	STATIC`O'SEAL	"
421	ALH	201P 281H 1200 206/H	`O'RING	"
422	ALH	201P 281H 1200 207/H	`O'RING	"
423	ALH	201P 281H 1200 208/H	STATIC`O'SEAL	"
424	ALH	201P 281H 1500 204/H	`O'RING	"
425	ALH	201P 281H 2000 204/H	`O'RING	"
426	ALH	201P 281H 3000 209/H	`O'RING	"
427	ALH	201P 281H 3000 210/H	`O'RING	"
428	ALH	201P 285H 0000 205/H	`O'RING	"
429	ALH	201P 285H 0000 206/H	`O'RING	"
430	ALH	201P 285H 0000 207/H	`O'RING	"
431	ALH	201P 285H 1000 203/H	`O'RING	"
432	ALH	201P 291H 1000 201/H	`O'RING	DTD 458AGR A GR I
433	ALH	201P 291H 1000 203/H	`O'RING	60C7
434	ALH	201P 291H 1000 204/H	`O'RING	"
435	ALH	201P 291H 4100 201/H	`O'RING	DTD 458AGR A GR I
436	ALH	201P 291H 4100 202/H	`O'RING	"
437	ALH	201P 291H 4100 203/H	`O'RING	"
438	ALH	201P 291H 4100 204/H	`O'RING	"
439	ALH	201P 291H 4500 215/H	`O'RING	23B7

440	ALH	201P 321H 1000 207/H	FORWARD RUBBER BUSH	HM 4927
441	ALH	201P 321H 1000 407/H	REAR RUBBER BUSH	"
442	ALH	201P 521H 3201 001/H	RUBBER SPIGOT FITTING ASSEMBLY	31B5
443	ALH	201P 622H 0000 209/H	`O'RING	23B7
444	ALH	201P 636H 0000 801/H	`O'RING	"
445	ALH	201P 636H 0000 803/H	`O'RING	"
446	ALH	201P 636H 0000 807/H	`O'RING	AMS7276A
447	ALH	201P 636H 0000 809/H	`O'RING	23B7
448	ALH	201P 636H 0000 815/H	`O'RING	AMS 7276A
449	ALH	201P 636H 0003 203/H	`O'RING	AMS 7276A
450	ALH	201P 636H 0009 409/H	`O'RING	"
451	ALH	201P 636H 0009 701/H	`O'RING	23B7 OR AMS 7276A
452	ALH	201P 636H 0009 703/H	`O'RING	"
453	ALH	201P 636H 0009 705/H	`O'RING	"
454	ALH	201P 636H 0009 707/H	`O'RING	"
455	ALH	201P 636H 0009 709/H	`O'RING	"
456	ALH	201P 636H 0009 711/H	`O'RING	"
457	ALH	201P 636H 0009 713/H	`O'RING	23B7 OR AMS 7276A
458	ALH	201P 636H 0009 717/H	`O'RING	AMS 7276A
459	ALH	201P 636H 0009 719/H	`O'RING	"
460	ALH	201P 636H 0009 721/H	`O'RING	"
461	ALH	201P 636H 0009 723/H	`O'RING	"
462	ALH	201P 636H 0009 725/H	`O'RING	"
463	ALH	201P 636H 0009 729/H	`O'RING	"
464	ALH	201P 636H 0009 731/H	`O'RING	"
465	ALH	201P 636H 0009 733/H	`O'RING	"
466	ALH	201P 636H 0009 735/H	`O'RING	"
467	ALH	201P 636H 0009 737/H	`O'RING	"
468	ALH	201P 636H 0009 741/H	`O'RING	"
469	ALH	201P 636H 0009 745/H	`O'RING	"
470	ALH	201P 636H 0009 749/H	`O'RING	"
471	ALH	201P 636H 0009 751/H	`O'RING	"
472	ALH	201P 636H 0009 753/H	`O'RING	"
473	ALH	201P 636H 0009 801/H	`O'RING	23B7
474	ALH	201P 636H 0009 803/H	`O'RING	"
475	ALH	201P 636H 0009 807/H	`O'RING	"
476	ALH	201P 636H 0009 809/H	`O'RING	"
477	ALH	201P 636H 0009 811/H	`O'RING	"
478	ALH	201P 636H 0009 815/H	`O'RING	"
479	ALH	201P 636H 0009 817/H	`O'RING	"
480	ALH	201P 636H 0009 819/H	`O'RING	"
481	ALH	201P 636H 0009 821/H	`O'RING	"
482	ALH	201P 636H 0009 823/H	`O'RING	"

483	ALH	201P 636H 0009 825/H	`O'RING	"
484	ALH	201P 636H 0009 829/H	`O'RING	"
485	ALH	201P 636H 0009 831/H	`O'RING	"
486	ALH	201P 636H 0009 841/H	`O'RING	"
487	ALH	201P 636H 0009 843/H	`O'RING	"
488	ALH	201P 636H 0009 845/H	`O'RING	"
489	ALH	201P 636H 0009 851/H	`O'RING	"
490	ALH	201P 636H 0020 204/H	GASKET	60C7
491	ALH	201P 636H 0020 205/H	GASKET	"
492	ALH	201P 636H 0021 221/H	`O'RING	"
493	ALH	201P 652H 0000 801/H	`O'RING	AMS 7276A
494	ALH	201P 652H 0000 802/H	`O'RING	"
495	ALH	201P 653H 0010 203/H	GASKET	60C7
496	ALH	201P 762H 1100 202/H	RUBBER BUSH	"
497	ALH	201P 795H 0000 201/H	`O'RING	23B7
498	ALH	201P 795H 0000 203/H	`O'SEAL	"
499	ALH	201X 004H 6230 207/H	`O'RING	"
500	ALH	201X 672H 3150 213/H	SPACER-RUBBER	HM 4931
501	ALH	201X 672H 3150 214/H	SPACER-RUBBER	"
502	ALH	201Y 281H 3010 202/H	`O'RING	21B6
503	ALH	201Y 283H 1100 203/H	`O'SEAL	"
504	ALH	201Y 286H 0000 205/H	`O'RING	"
505	ALH	201Y 286H 0000 206/H	`O'RING	"
506	ALH	201Y 636H 0000 813/H	`O'RING	AMS 7276A
507	ALH	201P 656H 3000 203/H	ELASTOMERIC BUSH	31B6
508	ALH	201X 287H 0000 221/H	STATIC`O'RING	21B6
509	ALH	201X 281H 5000 202/H	RUBBER SLEEVE	"
510	Ch/Ck	A29-60700/H	RUBBER SEAL	20A7
511	Ch/Ck	AN 931-16-22/H	GROMMET	BACM 573D GR 45
512	Ch/Ck	A5916.0836/H	`O'RING	DTD 458A GR.A GR.I
513	Ch/Ck	JEE 17Z/H	RUBBER SEAL	20A7
514	Ch/Ck	JEE 20Z/H	RUBBER SEAL	"
515	Ch/Ck	JE 37Z/H	RUBBER SEAL	"
516	Ch/Ck	JE 48Z/H	`O'RING	"
517	Ch/Ck	SE 3160S.25.22.068/H	STOP RUBBER	31B5
518	Ch/Ck	1.5 X 5.9/H (M 06562-2)	RUBBER SEAL	23B7
519	Ch/Ck	1.9 X 4.2/H	RUBBER SEAL	21A7
520	Ch/Ck	1.9 X 8.9/H (M 06204-2)	RUBBER SEAL	23B7
521	Ch/Ck	2 X 5.5/H (M 06204-3)	`O'RING	"
522	Ch/Ck	2 X 8/H (M 06204-4)	SEAL	"
523	Ch/Ck	2 X 10.5/H	`O'RING	20B8
524	Ch/Ck	2 X 16/H	`O'RING	"
525	Ch/Ck	2 X 16.2 /H	RUBBER SEAL	"
526	Ch/Ck	2 X 16.2/H (M 06204-5)	RUBBER SEAL	23B7

527	Ch/Ck	2 X 22.5/H (M 06204-6)	SEAL	"
528	Ch/Ck	2 X 27/H (M 06204-7)	SEAL	"
529	Ch/Ck	2 X 27.4/H (M 06204-8)	SEAL	"
530	Ch/Ck	2 X 30.9/H (M 06204-9)	RUBBER SEAL	"
531	Ch/Ck	2 X 32/H (M 06204-10)	RUBBER SEAL	"
532	Ch/Ck	2 X 48/H (M06562-3)	SEAL	"
533	Ch/Ck	2 X 52/H	`O'RING	20B8
534	Ch/Ck	2 X 56.9/H (M 06204-11)	RUBBER SEAL	23B7
535	Ch/Ck	2 X 65.5/H (M 06204-12)	RUBBER SEAL	"
536	Ch/Ck	2 X 66.6/H (M 06204-13)	SEAL	"
537	Ch/Ck	2 X 74.5/H (M 06204-14)	SEAL	"
538	Ch/Ck	2 X 77.4/H (M 06204-15)	RUBBER SEAL	"
539	Ch/Ck	2 X 85/H (M06204-16)	RUBBER SEAL	"
540	Ch/Ck	2 X 86.2/H (M 06204-17)	SEAL	"
541	Ch/Ck	2 X 87.2/H (M 06204-18)	SEAL	23B7
542	Ch/Ck	2 X 90/H (M 06204-19)	RUBBER SEAL	"
543	Ch/Ck	2 X 100/H (M060204-20)	RUBBER SEAL	"
544	Ch/Ck	2 X 112/H (M 06204-21)	RUBBER SEAL	"
545	Ch/Ck	2 X 127.5/H (M 06562-4)	RUBBER SEAL	"
546	Ch/Ck	2 X 200/H (M 06204-22)	SEAL	"
547	Ch/Ck	2 X 211/H (M 06204-23)	SEAL	"
548	Ch/Ck	2.2 X 24.8/H (M 06204-24)	RUBBER SEAL	"
549	Ch/Ck	2.2 X 57/H (M 06562-5)	RUBBER SEAL	24B7
550	Ch/Ck	2.46 X 19.18/H (M06562-6)	SEAL	23B7
551	Ch/Ck	2.5 X 8.5/H (M 06204-25)	SEAL	"
552	Ch/Ck	2.7 X 16.9/H (818-10-130)	RUBBER SEAL	21A7
553	Ch/Ck	3 X 9.4/H	SEAL	24B7
554	Ch/Ck	3 X 12/H (M 06562-8)	RUBBER SEAL	23B7
555	Ch/Ck	3 X 60/H (M 06204-27)	RUBBER SEAL	"
556	Ch/Ck	3.6 X 18.3/H (818-10-150)	RUBBER SEAL	21A7
557	Ch/Ck	3.6 X 19.8/H (81810-160)	SEAL	24B7
558	Ch/Ck	3.6 x 26.2/H (M 06204-29)	RUBBER SEAL	23B7
559	Ch/Ck	3.6 X 29.3/H (818-10-220)	RUBBER SEAL	21A7
560	Ch/Ck	3.9 X 19.1/H (M06204-30)	RUBBER SEAL	23B7
561	Ch/Ck	5 X 13.8/H (M 06204-3)	RUBBER SEAL	"
562	Ch/Ck	3022/H	RUBBER`O'RING	21A6
563	Ch/Ck	3259/H	`O'RING	20B6
564	Ch/Ck	50462/H	RUBBER BUSH	21A7
565	Ch/Ck	80631/H	RUBBER`O'RING	"
566	Ch/Ck	81215/H	`O'RING	21A7
567	Ch/Ck	81486/H	RUBBER`O'RING	"
568	Ch/Ck	2-73017/H	CAP	31B5
569	Ch/Ck	22-88008/H	RUBBER SEAL	20A7
570	Ch/Ck	25-88008/H	RUBBER SEAL	"
571	Ch/Ck	315A-21-28-020/H	RING ASSY. SHOCK ABSORBER	31B6

572	Ch/Ck	319A-62-01-004-1/H	RUBBER PLUG	21A9
573	Ch/Ck	1549.0099.20/H	`O'RING	20A7
574	Ch/Ck	201P 636H 0000 807/H	`O'RING	23B7
575	Ch/Ck	3130-13-40-908/H	RUBBER SEAL	21A7
576	Ch/Ck	3130-13-50-902/H	COVER	23B7
577	Ch/Ck	3130-23-20-008/H	GROMMET	BACM 573D GR 45
578	Ch/Ck	3130-23-40-001/H	PLUG	20B6
579	Ch/Ck	3130-26-21-556/H	RUBBER SEAL	50D6
580	Ch/Ck	3130-46-10-007/H	MOLDED STRIP	31B8
581	Ch/Ck	3130-46-10-566/H	RUBBER SEAL	60C7
582	Ch/Ck	3130-60-10-101/H	RUBBER FILTER	21A9
583	Ch/Ck	3130-67-10-902/H	PLUG	"
584	Ch/Ck	3130-82-21-015/H	GROMMET	20A6
585	Ch/Ck	3160-12-10-904/H	RUBBER SEAL	23B7
586	Ch/Ck	3160-12-10-909/H	RUBBER SEAL	"
587	Ch/Ck	3160-21-15-011/H	STOP RUBBER FLOOR HATCH	31B6
588	Ch/Ck	3160-29-08-618/H	RUBBER SEAL	50D7(5B70)
589	Ch/Ck	3160S-35-30-516/H	SEAL,RUBBER	31B8
590	Ch/Ck	3160-51-20-002/H	SEAL	23B7
591	Ch/Ck	3160-51-20-003/H	SEAL	24B7
592	Ch/Ck	3160-53-11-123/H	RUBBER SEAL	23B7
593	Ch/Ck	3160-62-10-900/H	RUBBER SEAL	"
594	Ch/Ck	3160-62-10-901/H	RUBBER SEAL	"
595	Ch/Ck	3160-65-10-902/H	`O'RING	23B7
596	Ch/Ck	3160-66-00-901/H	SEAL,OIL LEVEL SIGHT	"
597	Ch/Ck	3160-66-00-902/H	RUBBER SEAL	"
598	Ch/Ck	3160-66-00-903/H	CAP	"
599	Ch/Ck	3160-66-00-904/H	SEAL-DRUM	"
600	Ch/Ck	3160-67-10-903/H	RUBBER SEAL	"
601	Ch/Ck	3160-73-39-001/H	RUBBER SEAL	50D7(5B70)
602	Ch/Ck	3160-73-39-002/H	GASKET	50D7
603	Ch/Ck	3160S-65-10-901/H	RUBBER SEAL	23B7
604	Ch/Ck	4214-3/H	JOINT	DTD 560 GR.C Q/P
605	Ch/Ck	319A-75-10-037/H	SEAL	23B7
606	Ch/Ck	SE 3130S. 73.71.901/H	SEAL,OIL SIGHT GAUGE	20A5
607	Ch/Ck	SMC-37/H	SEAL RUBBER	24B7
608	Ch/Ck	SMC-45/H	SEAL RUBBER	24B7
609	Jaguar	CSP 4CD-021/H	`O'RING	DTD 560 Gr 'C' Q/P
610	Jaguar	CSP 4CD-115/H	RUBBER`O'RING	"
611	Jaguar	CSP 4CD -121/H	`O'RING	"
612	Jaguar	CSP 4CD -126/H	`O'RING	"
613	Jaguar	CSP 4CD-131/H	`O'RING	"
614	Jaguar	CSP 4CD-138/H	`O'RING	"

615	Jaguar	CSP 4CD- 218/H	`O'RING	"
616	Jaguar	CSP 4CD - 222/H	`O'RING	"
617	Jaguar	CSP 4CD-327/H	`O'RING	DTD 560 Gr 'C' Q/P
618	Jaguar	CSP 4CD-329/H	`O'RING	"
619	Jaguar	CSP 4DE- 223/H	`O'RING	60C7
620	Jaguar	CSP 4DE- 226/H	`O'RING	"
621	Jaguar	CSP 4 HF-213/H	ELASTOMERIC`O'RING SEAL	"
622	Jaguar	FA 1947-2/H (M 21344)	CAP	31B5
623	Jaguar	HTE 1884/H	`O'RING	DTD 5509 GR.C
624	Jaguar	HTE-1885/H	`O'RING	"
625	Jaguar	HTE 441-32-4/H	RUBBER`O'RING	DTD 5509 GR.B
626	Jaguar	M 20551/H	SEAL	21B6
627	Jaguar	M 20467-4/H	`O'RING	DTD 560 Gr 'C' Q/P
628	Jaguar	M 20956/H	`O'RING	DTD 5509 GR. B
629	Jaguar	M 20965/H	`O'RING	21A6
630	Jaguar	M 21317 /H (CSP 5B 4 BC)	GROMMET	DTD 5509 GR D
631	Jaguar	SP 93/C4/H	GROMMET	DTD 5509 GR.D
632	Jaguar	SP 93/D10/H	GROMMET	"
633	Jaguar	SP 93/D12/H	GROMMET	"
634	Jaguar	SP 93/D16/H	GROMMET	"
635	Jaguar	SP 93/D20/H	GROMMET	"
636	Jaguar	SP 93/E20/H	GROMMET	"
637	Jaguar	SP 93/F10/H	GROMMET	"
638	Jaguar	R 6a/H	RUBBER SEAL	50D7
639	Jaguar	R 19/H (M 20827)	`O'RING	"
640	Jaguar	R 30/H (M 20828)	`O'RING	"
641	Jaguar	R 38C/H	`O'RING	60C7
642	Jaguar	R 30PB 701/H (M 20872)	`O'RING	50D7
643	Jaguar	R 30 SIL 1013/H	RUBBER`O'RING	"
644	Jaguar	R 33 SL 1013/H (M 20873)	RUBBER`O'RING	"
645	Jaguar	R 33 DF-150/H (M 20876)	RUBBER`O'RING	60C7
646	Jaguar	R 38 SL 1013/H(M 20874)	RUBBER`O'RING	50D7
647	Jaguar	RN 20/H	RUBBER`O'RING	"
648	Jaguar	RN 22/H	RUBBER`O'RING	50D7
649	Jaguar	RN 29/H (M 20885)	`O'RING	50D7
650	Jaguar	RN 32/H (M 20886)	RUBBER`O'RING	"
651	Jaguar	RN 33/H	RUBBER`O'RING	"
652	Jaguar	RN 40/H (M 20887)	RUBBER`O'RING	"
653	Jaguar	RN 43/H	`O'RING	"
654	Jaguar	RN 47/H (M 20888)	RUBBER`O'RING	"
655	Jaguar	RN 70/H (M 20889)	RUBBER`O'RING	"
656	Jaguar	SR 137/H (M 20882)	`O'RING	31B6
657	Jaguar	020 A4/H (M 20880)	RUBBER`O'RING	50D6
658	Jaguar	020 F4/H (M 20878)	RUBBER`O'RING	20B6

659	Jaguar	025 A4/H	RUBBER`O'RING	50D6
660	Jaguar	025 F4/H	RUBBER`O'RING	21A7
661	Jaguar	032 A4/H (M 20881)	RUBBER`O'RING	50D6
662	Jaguar	032 F4/H (M 20879)	RUBBER`O'RING	20B6
663	Jaguar	040 F4/H (M 20883)	`O'RING	"
664	Jaguar	050 F4/H (M 20884)	RUBBER`O'RING	"
665	Jaguar	121E-23-125-081/H	PAD	50D7
666	Jaguar	121E-23-125-082/H	PAD	50D7
667	Jaguar	121E-23-130-230/H	TAMPON STOPPER	31B8
668	Jaguar	121E-23-637-060/H	SHOCK MOUNT	"
669	Jaguar	121E-52-125-250/H	WASHER	20B6
670	Jaguar	121E-52-500-440/H	WASHER	BACM 573 Gr 45
671	Jaguar	121E-52-500-640/H	SEALING RING	BACM 573 Gr 65
672	Jaguar	121E-63-230-030/H	RUBBER SEAL	31B5
673	Jaguar	121E-63-530-040/H	CABLE SEAL	60C7
674	Jaguar	121E-77-325-400/H	SHOCK MOUNT	31B4
675	Jaguar	324-58206/H	RUBBER SEAL	DTD 560 Gr 'C' Q/P
676	Jaguar	58244 'A' /H	COVER TERMINAL	DTD 458 A Gr A Gr I
677	Jaguar	75-20-0264/H	GAITER (FUEL PIPE)	DTD 5509 GR.C
678	Jaguar	75-20-0266/H	GAITER (FUEL PIPE)	DTD 5509 Gr C
679	Mirage	R00720X190A20A5/H	`O'RING	20A5
680	Mirage	GN 30-2/H	GASKET	24B7
681	Mirage	MBEU 35487/H	RING SEALING	20B8
682	Kiran	150-29114 A	TAIL SKID BUMPER	DTD 560 Gr 'C' Q/P
683	Kiran	150-35326-4	`O'SEAL	DTD 458A Gr A Gr I
684	Kiran	150-37343-8	`O'SEAL	"
685	Kiran	324-58211	RUBBER SEAL	DTD 560 Gr 'C' Q/P
686	Kiran	324-58223	RUBBER SEAL	DTD 560 Gr D Q/P
687	Kiran	324-59207	RUBBER SEAL	DTD 560 Gr 'C' Q/P
688	Kiran	394539	RUBBER SEAL	"
689	Kiran	701030500	RUBBER SEAL	20B8
690	Kiran	750030105	`O'RING	DTD 458 A Gr A Gr I
691	Kiran	750030702	RUBBER`O'RING	"
692	Kiran	750030706	RUBBER`O'RING	"
693	Kiran	750150105	RUBBER`O'RING	"
694	Kiran	813016	SEAL	"
695	Kiran	813017	SEAL	"
696	Kiran	AGS 838/9	WASHER	"
697	Kiran	BM404-8-39	RUBBER SEAL	"
698	Kiran	DAS 2118-6	SEAL	"
699	Kiran	DAS 2137-12	`O'RING	"

700	Kiran	GD 1480/2C (M20472-2)	STRUD	DTD 560 Gr 'C' Q/P
701	Kiran	GD 1480/3C (M20472-3)	STRUD	"
702	Kiran	GD 1480/4C (M20472-4)	STRUD	"
703	Kiran	H 502114	SEAL	DTD 458A GR.A GR.I
704	Kiran	M 20588-2	RUBBER`O'RING	50D6
705	Kiran	M 20588-3	RUBBER`O'RING	"
706	Kiran	M 20588-4	RUBBER`O'RING	"
707	Kiran	M 20839 (FA 1947-3)	RUBBER BUSH	31B5
708	Kiran	O/DLE/M1400	SELECTOR VALVE	DTD 560 Gr D Q/P
709	Kiran	SP 900-7	`O'RING	DTD 560 Gr 'C' Q/P
710	Kiran	SP 910-22 (M20902)	`O'SEAL	"
711	Kiran	SP 916-9 (M20901)	`O'SEAL	"
712	Kiran	SP 93/A6	GROMMET	DTD 5509 GR.D
713	Kiran	SP 93/A8	GROMMET	"
714	Kiran	SP 93/A12	GROMMET	"
715	Kiran	SP 93/A16	GROMMET	"
716	Kiran	SP 93/A18	GROMMET	"
717	Kiran	SP 93/A24	GROMMET	"
718	Kiran	SP 93/A32	GROMMET	"
719	Kiran	SP 93/B6	GROMMET	"
720	Kiran	SP 93/B8	GROMMET	"
721	Kiran	SP 93/B16	GROMMET	"
722	Kiran	SP 93/B24	GROMMET	"
723	Kiran	SP 93/B32	GROMMET	"
724	Kiran	SP 93/C6	GROMMET	"
725	Kiran	SP 93/C8	GROMMET	"
726	Kiran	SP 93/C10	GROMMET	"
727	Kiran	SP 93/C32	GROMMET	"
728	Kiran	SP 95/A20	GROMMET	DTD 5514 Gr 'D'
729	Kiran	DAS 2138/1	SEAL	DTD 458A GR.A GR.I
730	Kiran	11138Y2	SEAL	21B8
731	Kiran	H 500422/H	RUBBER SEAL	DTD 458A GR.A GR.I
732	Kiran	409351	SEAL	DTD 458A GR.A GR.I
733	Kiran	ADS 415/6	`O'RING	20A9
734	Kiran	ADS 415/8	`O'RING	20A9
735	Kiran	HTE 623-007	SEAL	DTD 5509 GR.C
736	HS 748	HS 748-3057	RUBBER CLEAT	31B8
737	HS 748	HS 748-4284	RUBBER SEAL	DTD 458A GR.B1
738	HS 748	HS 748-4329	RING SEAL	21B8
739	HS 748	HS 748-4468	RING OIL SEALING	21A8
740	HS 748	HS 748-4507	SEAL	21A8
741	HS 748	HS 748-4509	OIL SEAL	"

742	HS 748	HS 748-4603	RUBBER SEAL	DTD 458A GR.B1
743	HS 748	HS 748-4604	RUBBER SEAL	DTD 458A GR.A1
744	HS 748	HS 748-4605	RUBBER SEAL	DTD 458A GR.B1
745	HS 748	HS 748-4609	RUBBER SEAL	31B8
746	HS 748	HS 748-4695	RUBBER SEAL	DTD 458A GR.B1
747	HS 748	HS 748-4696	RUBBER SEAL	21A8
748	HS 748	HS 748-4736	`O'RING	DTD 458A GR.B1
749	HS 748	HS 748-4737	`O'RING	DTD 458A GR.A1
750	HS 748	HS 748-4739	RUBBER SEAL	DTD 458A GR.B1
751	HS 748	HS 748-4740	RUBBER SEAL	"
752	HS 748	HS 748-4741	FLAT SEAL	"
753	HS 748	HS 748-4742	RUBBER SEAL	"
754	HS 748	HS 748-4744	SEAL	DTD 458A GR B GR I
755	HS 748	HS 748-4745	`O'-RING	"
756	HS 748	HS 748-4746	RING SEAL	21A8
757	HS 748	HS 748-4747	RING SEAL	DTD 458A GR.B1
758	HS 748	HS 748-4748	`O'RING	"
759	HS 748	HS 748-4749	SEAL	"
760	HS 748	HS 748-4750	`O'-RING	"
761	HS 748	HS 748-4751	RUBBER SEAL	"
762	HS 748	HS 748-4752	WASHER SEAL	31B8
763	HS 748	HS 748-4753	RING SEAL	DTD 458A GR.B1
764	HS 748	HS 748-4755	SEALING RING	DTD 458A GR.A1
765	HS 748	HS 748-4759	RUBBER SEAL	DTD 458A GR.AI
766	HS 748	HS 748-4760	RING OIL SEAL	21A8
767	HS 748	HS 748-4761	RING OIL SEAL	"
768	HS 748	HS 748-4765	RING SEAL	DTD 458A GR.B1
769	HS 748	HS 748-4768	`O'RING	31B8
770	HS 748	HS 748-4772	RING SEAL	21A8
771	HS 748	HS 748-4773	RING SEAL	"
772	HS 748	HS 748-4774	`O'RING	"
773	HS 748	HS 748-4775	RING SEAL	31B8
774	HS 748	HS 748-4778	RING SEAL	21A8
775	HS 748	HS 748-4779	GASKET	"
776	HS 748	HS 748-4781	GASKET	23B7
777	HS 748	HS 748-4788	GROMMET	31B8
778	HS 748	HS 748-4789	GASKET	"
779	HS 748	HS 748-4790	GASKET	DTD 5509 GR.B
780	HS 748	HS 748-4791	GASKET	31B8
781	HS 748	HS 748-4796	GASKET	31B6
782	HS 748	HS 748-4911	BUSH	50D6
783	HS 748	HS 748-4913	RUBBER PAD	50D6
784	HPT 32	HPT 32 -5059	WASHER	31B8
785	HPT 32	HPT 32 -5060	`O'RING	21A7
786	HPT 32	HPT 32 -5061	`O'RING	"

787	HPT 32	HPT 32 -5062	`O'RING	21A8
788	HPT 32	HPT 32 -5064	PACKING SEAL	"
789	HPT 32	HPT 32 -5067	`O'RING	"
790	HPT 32	HPT 32 -5069	`O' RING	61D6
791	HPT 32	HPT 32 -5068	`O'RING	21B6
792	DORNIER	DO 228-8087/A	RUBBER SHEET	50D5
793	DORNIER	DO 228-8089/A	RUBBER SHEET	"

11 JOINT SERVICES SPECIFICATION FOR RUBBER COMPOUNDS

Many of the rubber compounds in service are indigenized. A close look of these specifications would indicate that apart from the commonality of the base of the elastomer and its application, even the properties required in many of the specification are similar. This justifies the need to rationalization of different specifications and to evolve common Indian specifications.

Presently numerous rubber compounds exist which meet the requirements of individual specifications like British (DTD/BS), American (MIL/Federal), French (NFL), Russian (GOST), Rolls Royce (MSRR), Lucas Standards etc. The Joint services specification (JSS) has brought out these different specifications under one fold.

In view of the above, CEMILAC has taken up task of the rationalization of various airborne stores through Aero Stores Standardization Sub Committee (Aero SSSC) under CCSSC, which in turn comprised eight working groups. Working Group of Rubber Compounds is one among them. 20 Joint Services Specifications have been developed by this group over last five years. Exhaustive efforts have been already made to rationalize these specifications of different kinds. Table 33 shows the JSS of different rubber compounds.

Table 33 Joint Services Specification of rubber compounds

S. No.	JSS No.	DESCRIPTION	RELATED SPECIFICATION	POSSIBLE APPLICATIONS
1	9320:02	NITRILE I	MSRR 5008 Lucas Std 6-18-59	Aircraft application
2	9320:03	NITRILE II	DTD 485A GR B Gr1 DTD 5509 GR B	Aircraft application
3	9320:05	FLUORO CARBON I	IRP 1287 IRP 1305 NFL-17-101A-60C7 MSRR 9450	Manufacture of rubber items in media of ATF, Hydraulic liquid & air in western aero engine & Helicopter applications
4	9320:06	SILICONE I	IRP 1266,14P2 AND 5P 129 (Ty-38-005-1166-87) NFL-17-101A-50D5 DTD-5582A Gr 50 DTD-5531A Gr 50 MSRR 9453	Manufacture of rubber seals, ‘O’ rings & gaskets for Jaguar aircraft
5	9320:07	SILICON II	NFL-17-101A-50D6 BACE 430 DTD-5531A Gr 60 DTD-5582A Gr 60 IRP 1338	Aeronautical & Aero engine applications

6	9320:08	NITRILE III	DTD 560 GR ‘C’ QLY ‘P’ DTD 458A GR ‘A’ GR ‘1’ DTD 5509 GR ‘C’ 1078 A – RUSSIAN	Manufacture of static seals in hydraulic and fuel system
7	9320:09	NITRILE IV	NFL-17-101A-20B6 NFL-17-101A-21B6 Russian spec 51-1536	Aircraft application
8	9320:10	NITRILE V	NFL-17-101A-20A7 NFL-17-101A-20B7 NFL-17-101A-42B7 9831, DRLM-21 A4-Russian	Manufacture of sealing rings
9	9320:11	NITRILE VI	DTD 5509 GR ‘D’ NFL-17-101A-20A6 NFL-17-101A-21A6	items for aeronautical & aero engine applications
10	9320:12	SILICONE III	IRP 1285 IRP 1401 NFL-17-101A-50D7 MSRR 9492 DTD 5531 Gr 70 DTD 5582 Gr 70	‘O’ Rings, Gaskets and Washers for Kiran, ALH, LCA and similar applications
11	9320:13	FLUORO CARBON II	AMS 7276A AMS 7280C DTD 5612 Gr 80 DTD 5543 Gr E	Manufacture of Rubber seals to be used in air & fuel media
12	9320:16	HYPALON	HM 4926 ISSUE ‘D’	Mountings, Wire & cable jackets, gaskets, seals, de-icers
13	9320:17	NITRILE VII	HM 4885 MSRR 9495 NFL-17-101A-21A9 LUCAS 6-18-21	Aircraft application
14	9320:18	NEOPRENE II	DTD 551A Gr ‘D’ NFL-17-131A-31B6 BS 2725 Gr 60 MIL-R-6855 CLASS II Gr 60	Rubber items used in Aircraft & Helicopters
15	9320:19	NITRILE VIII	HM 4888 MSRR 9495 LUCAS 6-18-32 LUCAS 6-18-59	Aircraft application
16	9320:20	EPDM-01	HM 4927 Issue ‘A’	Manufacture of boots, seals and mounts
17	9320:21	POLYCHLOR O PRENE-03	NFL-17-131A-31B8 MIL-R-6855 Class II, Gr 80 BS 2752 Gr C6	Rubber items for Helicopter applications
18	9320:22	NITRILE IX	BACM 573 D Gr-45	Aircraft and Helicopter applications
19	9320:23	NITRILE X	BACM 573 D Gr-65	Aircraft and Helicopter parts

12 RUBBER / ELASTOMER COMPOUND / COMPONENTS

Some of the type approved elastomeric components are listed in Table 34 and the component photographs are shown in Figure 23.

Table 34 Some of the rubber / elastomeric compounds / component

photo No.	Rubber Compound	Governing Specification / TA number	Component Part No. / Part Name	Application	Project
1	EPDM	HM 4927/ 995	201P 321H 1000 207/H /FORWARD RUBBER BUSH	Skid landing gear	ALH
2	NITRILE	23B7	3160.66.00.904 / SEAL	Tail gear box	CHEETAH/ CHETAK
3	NITRILE	BACM 573D GRADE 45	3160.23.20.008 / GROMMET	Floor hatch assembly	CHEETAH/ CHETAK
4	NITRILE	23B7	2 × 48 / "O" RINGS	Tail drive shaft	ALH, CHEETAH/CHETAK, HS748
5	SILICONE	50D7	3160.73.39.001 / GASKET	Venture assembly	CHEETAH/ CHETAK
6	NITRILE	23B7	3160.51.20.002 / GASKET	Fuel tank assembly	CHEETAH/ CHETAK
7	NITRILE	DTD 458A Gr. 'A' Gr. '1'	58244 'A' / COVER TERMINAL	Electro pump set	JAGUAR
8	SILICONE	50D7	121E-23-125-081 / PAD	Electrical assembly	JAGUAR
9	FLUORO CARBON	60C7	201P 636H 0020 205 / GASKET	Oil site gauge	ALH
10	NEOPRENE	31B5	201P 521H 3201 001 / SPIGOT FITTING ASSEMBLY	Door assembly	ALH

Bush for ALH

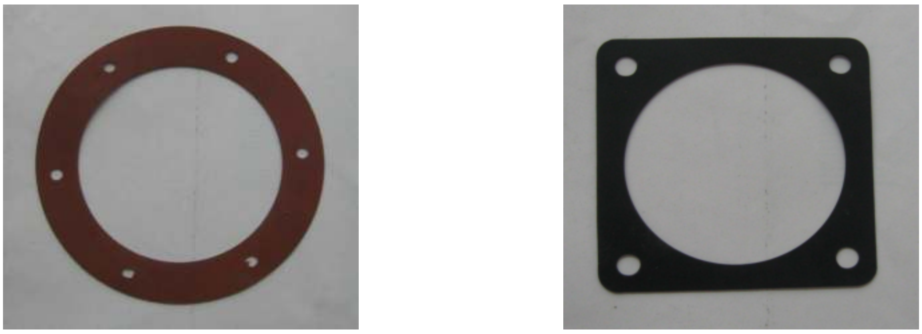
Seal for Cheetah / Chetak

Grommet for Kiran

"O" Rings for various projects

Figure 23 Some of the Rubber / Elastomeric compounds / component

Cover terminal for Jaguar



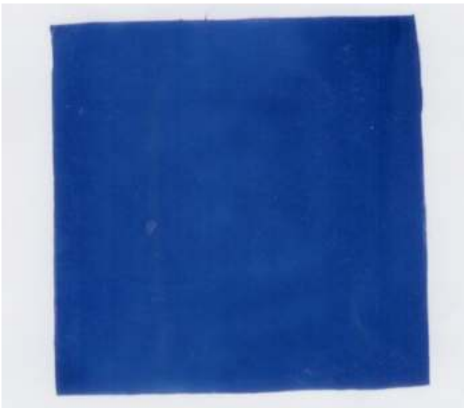
Gaskets for Chetak/Cheetah

Figure 23 Contd… Some of the Rubber / Elastomeric compounds / component

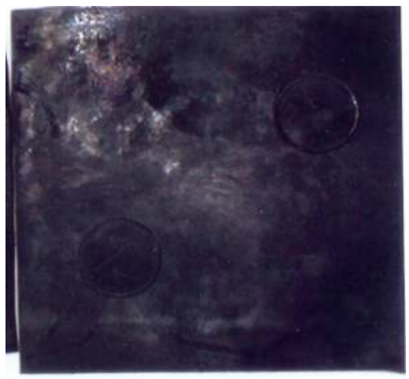
Gasket for ALH

Pad for Jaguar

Spigot fitting assembly for ALH



Fluorosilicone Rubber Compound



Nitrile base rubber compound

Figure 23 Contd… Some of the Rubber / Elastomeric compounds / component

13 CONCLUSION

This compendium is essentially an attempt to collate information on Rubbers / Elastomers used as seals, gaskets and similar components for aircraft / aeroengines of western origin besides those indigenized for similar requirements. This is not an exhaustive compilation but aimed to provide guidelines and serve as ready reference to indicate engineering properties, approvals accorded, and related specifications and source of supply.

14 ENCLOSURE I CLASSIFICATION OF RUBBER SEALS

Centre for Military Airworthiness and Certification
(C E M I L A C)
Defence Research & Development Organisation
Marathahalli Colony P.O
Bangalore-560 037

CEMILAC / 5390 / 3 / TCS Date: 8th July 20..

Sub: CEMILAC GUIDELINES ON "CLASSIFICATION OF RUBBER SEALS

1. Introduction:

Rubber seals are indispensable part of aircraft and its systems. Rubber seals are also found in very critical assemblies, failure of which, may cause catastrophic accident of aircraft. Hence classification of seals either "Critical or Non-Critical" is of great importance, as it helps in laying down the test requirements for according airworthiness clearance.

The Rubber Seals are being indigenised through different RCMAs. The procedure adopted for classification of seals by different RCMAs were reviewed by CEMILAC and found that different definitions are given to static and dynamic seals and classification of seals is also not uniformly understood by all.

In view of the above, the following guidelines are therefore issued for classification of seals. It should be noted that it is very difficult to evolve a common criteria for classification of seals used in different platforms as criticality of such parts is driven from end use point of view.

2. Classification:

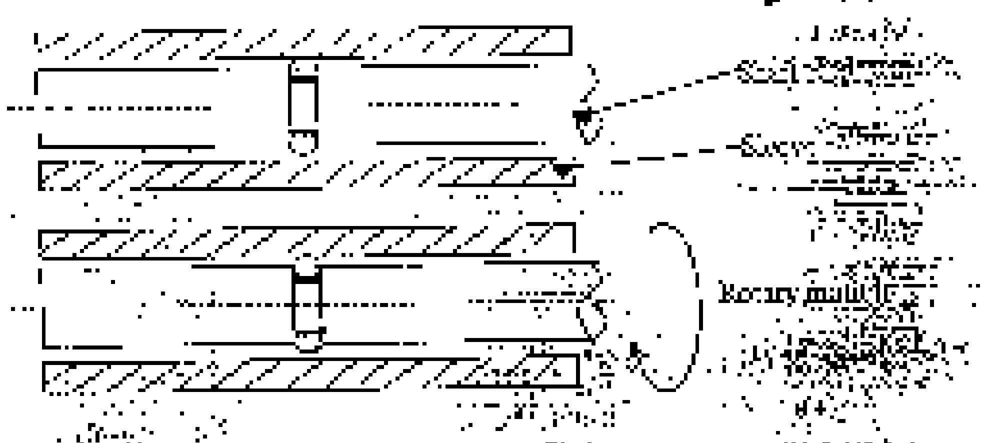
The important factors that need to be considered before attempting the classification of the Rubber seals are as given below:-

- Static or dynamic
- Resistance to Medium of working i.e Air, Fuel, Oil, Hydraulic Oil etc
- Resistance to arduous conditions of working i.e Temperature, Pressure
- Special applications

2.1 Static Seals :- Seals which do not have relative motion between them and its related components. Normally it has 90° parting line.

2.2 Dynamic Seals :- Seals which are part of rotating or translatory motion system. The seal by itself could be static but incase it has relative motion with its related part it can be regarded as dynamic seal. Normally dynamic seals are provided with 45° Parting line.

Illustrations of Dynamic seals



2.3 Criticality of Seals :- Critical seals are those, failure of which would cause leakage of Fuel, Oil or air which could affect safety of operation of the system. It is the application that defines its criticality. Generally most of the dynamic seals are considered as critical. Further seals that are subject to higher temperature and pressure could also be considered as critical as failure of such seals would invariably affect its performance and could lead to serious safety hazards. The seals could be considered critical under the following conditions.

i) Generally most of the dynamic seals are considered as critical.

ii) Static seals working in the Air medium with Pressure range of 0-[illegible] Kg/cm², Temperature range of -50 to [illegible] °C, Hardness (Shore) [illegible] and accuracy ± 0.1 mm Ring diameter considered as critical seals.

iii) Static seals working in the Oil medium with Pressure range of 0-150 Kg/cm², Temperature range of -55 to 200 °C, Hardness (Shore) [illegible] and accuracy ± 0.1 mm Ring diameter considered as critical seals.

iv) Static seals working in the Hydraulic Oil medium with Pressure range of 0-280 Kg/cm², Temperature range of -50 to 120 °C, Hardness

(Shore) >60 and accuracy ± 0.1mm Ring diameter considered as critical seals.

v). Static seals working in the Fuel medium with Pressure rage of 0-150 Kg/cm^2, Temperature range of -40 to 200 °C, Hardness (Shore) >60 and accuracy ± 0.1mm Ring diameter considered as critical seals.

2.4 Non-Critical Seals: - Non-Critical seals are those, failure of which would not affect the safety of operation of the system.

3. Classification of Seals:- Diagram depicting the classification of seals is placed at Enclosure-1 for clear understanding.

4. Clearance of Seals:- All static seals can be cleared in LTCC. In case of dynamic seals, besides fitment and functional test, endurance test should be carried out for approval. Thus dynamic seals, shall be referred to CEMILAC for approval.

Note: -

i). Identification / Categorization of seals as "Critical & Non-critical" should be discussed in LTCC, taking cognizance of all the above points mentioned at Para No. 2 & 3.

ii). Type Approval of all Rubber Compound used for manufacturing of seal is mandatory.

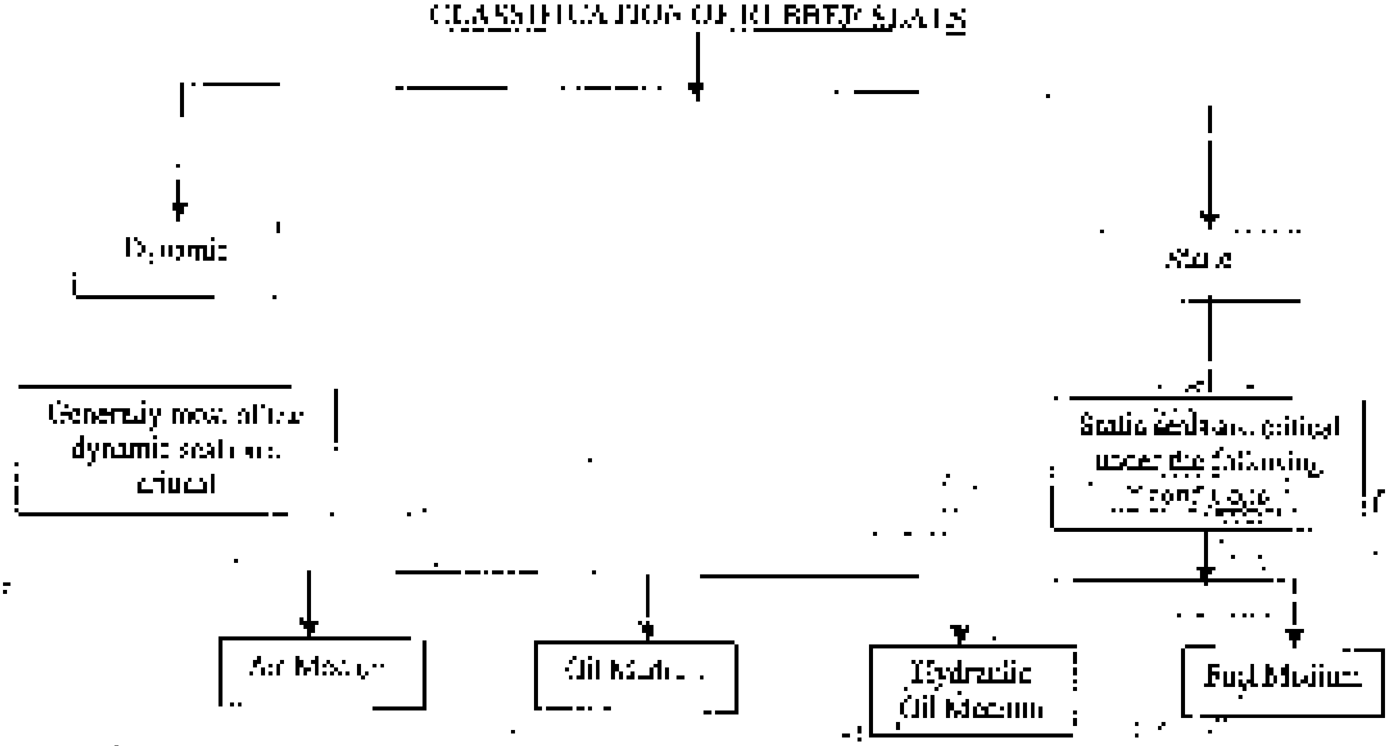
5. This guidelines supersedes the clearance aspects mentioned at "Para No. 4 of the Procedure for airworthiness clearance of indigenous rubber compounds and components for aeronautical applications" issued by CEMILAC vide letter No. CEMILAC / 2005 PF dated 4th July 2002. The necessary amendments for the above procedure will be issued shortly.

(JK SHARMA)
Chief Executive (Airworthiness)

Distribution: All GDs & All RCMAs

Enclosure-1

CLASSIFICATION OF RUBBER SEALS



	Air Medium	Oil Medium	Hydraulic Oil Medium	Fuel Medium
Pressure (kg/cm²)	0-30	0-150	0-280	0-150
Temperature :	-50 to 200 °C	-50 to 200 °C	-30 to 120 °C	-40 to 200 °C
Hardness	> 60	> 60	> 60	> 60
Accuracy (Ring Dia)	± 0.1mm	± 0.1mm	± 0.1mm	± 0.1mm

Note:-Seals are considered critical while operating near the extremities of the range indicated above.

References -

i. [illegible] "Rubber Materials Introduction and [illegible] Guide"

ii. British Standards Aviation Technology No. [illegible] on "Sealing of Aviation Hydraulic, Fuel, Oil and Pneumatic systems"

iii. CEMILAC procedure for airworthiness [illegible] components for commercial applications [illegible] No. CEMILAC/2005 [illegible] July 2005

Rubber Seals - 4 -

Phone :

GOVERNMENT OF INDIA
MINISTRY OF DEFENCE (R&D)
CENTRE FOR MILITARY AIRWORTHINESS & CERTIFICATION
MARATHAHALLI COLONY (POST)
BANGALORE - 560 037, INDIA

CEMILAC / 5390 / 2

Date: 18 March 2004

AIRWORTHINESS DIRECTIVE NO: 5

SUB: SHELF LIFE EXTENSION OF INDIGENOUS RUBBER SEALS

The shelf life of Indigenous rubber seals was restricted to 3 years vide D/Aero Letter No. Aero / Rd / 152 / 1607 dated 03 Oct 1973 and is also mentioned in the AIO No. 50, dated 03 ... 1973.

2. HQ Maintenance command vide letter No. MC/7146/1/Eng AV dated 4th Dec 2003, requested CEMILAC to review the shelf life policy for indigenous rubber seals presently in vogue and consider its extension. The present lifing policy of the Indigenous Rubber Seals has been reviewed by considering views of various RCMAs, HALs, JMSRDC & 3 BRD and the following modification to D/Aero's letter under reference on shelf life of indigenous rubber seals is hereby approved and issued:

3. The shelf life of the indigenous rubber seals will be as per the **Annexure-A** and the details are as follows:-

i). Indigenous rubber seals of all categories (categories are as per BS 3F 68, indicated at **Appendix-1**) – The initial storage life is assigned as 3 (Three) years only.

ii). Indigenous rubber seals of category of Group 'A' – NO FURTHER extension of shelf life is permitted.

iii). Indigenous rubber seals of category of Group 'B' - Extension in steps of 1 (one) year can be granted subjected to testing and limiting the total shelf life to maximum of 5 (five) years.

iv). Indigenous rubber seals of category of Group 'X' - One time extension of 2 (two) years can be granted subjected to testing and limiting the total shelf life to maximum of 5 (five) years.

Contd...2

v). Storage Conditions of indigenous rubber seals should be as per **Appendix-2.** (Reproduced from AFO No: 60, dated 03 June 1978)

vi). Laboratory tests to be carried out for shelf life extension of indigenous rubber seals should be as per **Appendix-3**. Results of test before and after ageing shall be compared and decision of shelf life extension may be taken in consultation with concerned RCMA.

vii). Tests for life extension to be carried out on or before expiry of shelf life.

4. Efforts to be made to procure Minimum Order Quantity (MOQ) of seals or Quantity required for three years based on Cumulative Annual Requirement to avoid life extension exercise.

5. The above directive supersedes all the earlier instructions on shelf life extension of indigenous rubber seals issued by CEMILAC as well as Directorate of Aeronautics.

(J K SHARMA)
Chief Executive (Airworthiness)

<u>Distribution</u>:

1. SO to AOM
2. SO to SMSO, HQ MC, Nagpur
3. SO to ADG, Army Aviation
4. DNAM
5. Director Aviation, Coast Guard HQrs

(Items 1–5:) With a request accordingly approve amend this modification relevant Service orders this subject.

6. DGAQA, New Delhi
7. Directors ADE, ADA, GTRE, CABS, CVRDE, DMSRDE, DRDL, ADRDE, ARDE, DEBEL, ASIEO & LRDE
8. All MDs, HAL
9. All GMs, HAL
10. All GDs, All RCMAs

Annexure-A

SHELF LIFE OF INDIGENOUS SEALS

CLASS	INITIAL STORAGE LIFE	EXTENSION PERIOD IN STEPS OF	MAXIMUM LIFE
Group A	3 Years	No extension is permitted	3 years
Group B	3 Years	1 Year Blocks - Maximum 2 Blocks	5 years
Group X	3 Years	2 Years	5 years

Note:-

i). Categorisation of rubber compounds as per BS 3F 68 and details indicated in Appendix-1.

ii). Storage conditions should be as per Appendix-2 (Reproduced from AFO No. 60 dated 03 June 1978) and testing as per Appendix-3 and in co-ordination with the concerned RCMA / CEMILAC.

iii). The period of extension can be reviewed after sufficient data is generated on life expired seals by DRD's / DMSRDE / HAL / RCMAs.

Appendix – 1

CATEGORIES OF RUBBER COMPOUNDS (AS PER BS [illegible])

GROUP 'A' [Moderate Susceptibility to deterioration by ageing]	GROUP 'B' [Low Susceptibility to deterioration by ageing]	GROUP 'X' [No periodic inspection required]
Natural	Acrylonitrile – butadiene (nitrile) blends of Acrylonitrile butadiene and polyvinyl chloride (nitrile / PVC)	Chlorosulphonated polyethylene
Polybutadiene	Epichlorohydrin	Ethylene – propylene
Polyisoprene	Polyacrylate	Fluorocarbon
Polyurethane	Polychloroprene (neoprene)	Fluorosilicone
Styrene – butadiene	Polyisobutylene – isoprene (butyl)	Silicone

[illegible]

STORAGE OF RUBBER SEALS AND OTHER COMPONENTS

(Reproduced from AFO No. 60 dated 03 June 1975)

Standard conditions of storage of rubber items used on aircraft are to be appended below.

2. Packaging:- Suitable packaging of rubber items in storage is necessary to minimize deterioration. Normally such items are received suitably packed from the manufactures. Packaging done by the manufacturers should not be removed till items is actually required for use. However, if original packaging has been undone for some reasons the items should be repacked in accordance with following instructions while they are in storage.

a). Small components should be enclosed in sealed envelopes.

b). Components which cannot conveniently be accommodated in envelopes shall be suitably enclosed or wrapped so as to prevent free access of air.

c). Packaging shall be accomplished under conditions which will ensure freedom from contamination by dust, oil grease etc., Attention shall be given to ensuring that the packet is efficiently sealed.

d). Components shall be free from strain (e.g adequately supported) and no part shall be tied or tagged

e). When it is necessary for components to be packed in assembly sets, such components shall be retained in their original identifying envelopes and the whole shall be inserted to the required quantity in the main package.

f). Dimension of Envelopes:- The preferred size of envelopes are 55, 150, 205 and 255 mm size.

g). Packing Materials:- Preference shall be given to the use of heat sealable opaque materials. Suitable materials are polythene coated kraft paper, aluminium foil / paper / polythene laminate and opaque polythene film. PVC film shall not be used. If for any reason a transparent or translucent material is used it shall be over wrapped with an opaque material.

3. Identification of Packaging :- Every package / envelope shall be marked with at least the following information shall be visible from outside of the package without breaking the seal.

a). Part Number
b). Material Specification Number
c) Quarter or year of cure
d) Life grouping (if applicable and known)
e). Quantity in package if more than one
f). Batch Number
g) Manufacturers identity

Note.- If the storage agency finds any of the above information missing on receipt of an item it should ask the provisioning agency to obtain supply the same.

4. Temperature:-

The storage temperature shall be between 10° C to 25° C. At temperature exceeding 25° C certain forms of deterioration may be accelerated sufficiently to affect the ultimate service life. The effects of very low temperature are not permanently deleterious to vulcanised rubber articles but they may become stiffer if stored at low temperature and care should be taken to avoid distorting them during handling at that temperature. When articles are taken from low temperature storage for immediate use their temperature should be raised to approximately 30° C throughout before they are put in to service.

5. Humidity

Moist conditions should be avoided; storage conditions should be such that condensation does not occur. For seals, incorporating fabric should not be allowed to become damp. The relative humidity should not exceed 65%.

6. Light

Rubber articles should be protected form light, in particular direct sunlight or strong artificial light with a high ultraviolet content. Unless the articles are packed in opaque containers it is advisable to cover windows of storage rooms with a red or orange coating or screen.

7. Oxygen & Ozone

Where possible rubber articles be protected from circulating air by wrapping, storage in airtight containers or other suitable means. This particularly applies to articles with large surface area to volume ratios, e.g. Rubber sheets etc. As Ozone, is particularly deleterious, storage rooms should not contain any equipment that is capable of generating Ozone, such as mercury lamps, high voltage electrical equipment, electric motors or other equipment which may give rise to electric sparks or silent electrical discharges.

8. Deformation

Vulcanised rubber should, wherever possible, be stored in a relaxed condition free from tension, compression or other deformation. The items should not be tightly strung together. Where articles are packaged in strain free condition they shall be stored in their original packaging.

9. Contact with liquid and semi-solid materials

Vulcanised rubber should not be allowed to come into contact with liquid or semi-solid materials, in particular, solvents, oils and greases, at any time during storage, unless so packed by the manufacturers.

10. Contact with metals

Certain metals in particular copper, manganese and iron are known to have deleterious effects on vulcanised rubber. Vulcanised rubber should, therefore, not be stored in contact with metals but should be protected by wrapping or by separation with a layer of suitable material, eg. Paper, polythene etc.

11. Contact between various rubbers

It is desirable that contact between vulcanised rubbers of different composition is avoided. This particularly applies to rubbers of different colours.

12. Articles with Rubber-to-Metal Bonds

The bonded metal should not come in contact with the vulcanised rubber other than at the bond. Any temporary protective coating used on the metal shall be such that it will not adversely affected the rubber or the bonds.

13. Rotation of Stocks

Vulcanised rubber should remain in store for as short a time as possible. Therefore, articles should be issued from store in strict rotation, so that articles remaining in store are those of latest manufacture or delivery.

14. Storage of Specific Items

Seals (including door seals) and extrusion.

(i). Lip type seals:- These shall always be stored in such a way as to prevent the sealing edges being damaged. On no account shall identity labels be tied to the actual components.

(ii). Extrusions and large components:- Coils of extruded items shall be protected by suitable rigid materials so that each coil is not distorted by its own weight or that of others stacked upon it. Large moldings, especially door seals, shall preferably be supported on hard board or thick cardboard.

Appendix – 3

LABORATORY TESTS REQUIRED FOR SHELF LIFE EXTENSION OF INDIGENOUS RUBBER SEALS

i). Visual Examination:

- a). Permanent distortions like creases or flats etc.,
- b). Mechanical Damages like cuts, tears, abraded areas or separation of rubber to fabric plies etc.,
- c) Changes in the surface conditions like hardening, softening or development of tackiness etc.,
- d). Blistering and peeling
- e) Corrosion of metal elements in bonded rubber to metal assemblies

ii). 20% Stretch test of rubber seals & Examination under X10 magnification

iii). Artificial Ageing & Bend test
- a) Accelerated air ageing
- b). Immersion in aromatic fuel
- c). After immersion in engine oil
- d). Immersion in Hydraulic oil

→ i). Test conditions to be specified according to the specification.

ii). 10% of deterioration permitted w.r.t specification limits.

iv). Hardness test, wherever applicable.

v). Tensile Strength and elongation %, wherever applicable.

vi). Compression set test, wherever applicable.

Note:- Tests to be carried out on or before expiry of shelf life

16 ENCLOSURE III TEST SCHEDULE OF RUBBER COMPONENT

RCMA HAL

TEST SCHEDULE

T.S.No. BRT-183
ISSUE No. 01
DATE: [illegible]
PAGES [illegible]

DEVELOPMENT OF RING SEAL TO PART NO. [illegible]

PROJECT : KIRAN

Cleared in the 15th LTCC meeting held on [illegible]

PREPARED BY	CHECKED BY	CO-ORDINATED BY	APPROVED BY
[illegible]	[illegible]	[illegible]	[illegible]
MANAGER [illegible]	SENIOR MANAGER (LABORATORY)	[illegible] (DEVELOPMENT)	[illegible]

TESTING PROFILE

[illegible]
ISSUE No. 01
DATE [illegible]
PAGES 2 OF 4

1. SCOPE

[illegible]

2. COMPONENT DETAILS

Sl. No.	Part No./ Part Name	Material Specification	Package	Contact medium	Nature of Criticality/ application
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Service Temperature : [illegible] (Nominally)

3. APPLICABLE DOCUMENTS/REFERENCES:

[illegible]

[illegible]

[illegible]

4.1 The following test methods will be followed:

Type of Test	Test Methods
[illegible]	[illegible]
Determination of Density	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

5. [illegible]

[illegible]

Sl. No.	Compound	Specification	Approved Reference (if any available)	Supplier
	[illegible]	[illegible]	[illegible]	[illegible]

HAL

TEST SCHEDULE

T.S.No. : [illegible]
ISSUE No. [illegible]
DATE : [illegible]
PAGE [illegible]

[illegible]

[illegible]

Batch Quantity [illegible]

[illegible] FINISHED PARTS

Part [illegible]

i) Visual Examination:

[illegible]

ii) Dimensional checks:

[illegible]

iii) [illegible] checks:

[illegible]

Tests	Requirements [illegible]
1. Initial Condition	
1.1 [illegible]	[illegible]
1.2 [illegible]	[illegible] value
2. Resistance to lubricating oil [illegible]	
2.1 [illegible]	
2.2 [illegible]	[illegible]
3. Resistance to heat ageing	
3.1 Heat ageing [illegible]	
3.1.1 [illegible] hardness	[illegible] + 15

[illegible]

7. PACKING

[illegible]

[illegible]

8. TYPE TESTS

[illegible]

9. STORAGE CONDITION

[illegible]

10. SHELF LIFE

[illegible]

17 ENCLOSURE IV FUNCTIONAL TEST SCHEDULE

[illegible]

REPORT ON DYNAMIC TESTING OF INDIGENOUS [illegible] SEALS DEVELOPED BY F&F FOR MAIN LANDING GEAR OF KIRAN AIRCRAFT

1 [illegible]

[illegible] cycles

2 REFERENCE DOCUMENT

[illegible]

[illegible] AN 6227-30 [illegible] AN 6227-[illegible]

[illegible] KIRAN AIRCRAFT MAIN LANDING GEAR.

2.2 [illegible]

REPORT ON DYNAMIC [illegible] SEALS [illegible] FOR MAIN LANDING GEAR OF KIRAN AIRCRAFT

3 [illegible]

[illegible] Landing Gear

Part No: [illegible]

4 TEST SETUP

4.1 [illegible] as shown in the photo [illegible]

4.2 [illegible] vertically on the fixture. The [illegible] was [illegible] by a servo controlled hydraulic actuator.

5 TEST PROCEDURE

5.1. The landing gear was charged with Nitrogen to [illegible]

5.2. The landing gear was compressed by 104 mm [illegible] position [illegible] piston extension was [illegible] A.

[illegible]	ISSUE	AMENDMENT NO	DATE
[illegible]	[illegible]	NIL	[illegible]

[illegible]

5.3. The landing gear was fully compressed by [illegible] such that the test [illegible] position of piston rod [illegible]. It was marked as B.

5.4. The [illegible] pressure was reduced and the landing gear was allowed to extend up to point A.

5.5. The stroke cycling was done between point A and B for 9000 cycles. The cycling rate was 0.16 Hz. A cooling time of 1 hour was allowed at the end of every 2000 cycles.

5.6 After every 1000 cycles, the piston was kept in fully extended position and the nitrogen was slowly discharged. Visual observations were made for any sign of oil frothing in hydraulic chamber. For continuing the cycling test, nitrogen was recharged to 250 psi.

5.7 The blackish material deposit on the piston was regularly wiped off after every 100 cycles. This was done as per the procedure suggested by the Designer and approved by GM (AQA) and CRI (A/C), vide Appendix 1.

6 TEST RESULTS

6.1. No external leakage was found.

6.2 No frothing was observed in the hydraulic chamber.

6.3 Some blackish stain was observed on the piston during the cycling, which was wiped off regularly as mentioned in 5.7. A sample of the residual material was collected and sent to Central Lab for investigation/material analysis. Lab report is enclosed as Appendix 2.

7 CONCLUSIONS

7.1. In the absence of external leakage and frothing, effectiveness of seal is considered satisfactory up to 9000 cycles.

E/OR-AE/118

HINDUSTAN AERONAUTICS LIMITED
ENGINE DIVISION - ELECTRICAL ACCESSORIES INSPECTION
FUEL PRESSURE WARNING SWITCH - ORPHEUS ENGINE
ASSEMBLY AND RIG TEST PROCEDURE SHEET

UNIT S.No.: 652   W.O.No.: 5055796026   DATE: 15-1-07

ENGINE: PR 51322/451   TYPE: [illegible]   HD: [illegible]

ASSEMBLY Ref: Chapter [illegible], Sec 8, Page [illegible] of [illegible] Manual

1. Fit overload plate to [illegible]
2. [illegible] assembly
3. [illegible] contact plate
4. [illegible] service
5. Pressure [illegible]
6. Set contact gap
   (i) Check [illegible] 10 PSI, [illegible] gap between the stator and moving contact [illegible]
   Record: [illegible]
7. [illegible]

TESTING

a. Diaphragm leakage test.
   Apply an air pressure of [illegible] for leak. — Found Satisfactory.

b. Pressure setting (Limit: 5 ± 0.5 PSI)
   Increasing: 5.2 PSI   5.1 PSI
   Decreasing: 5.0 PSI   5.0 PSI

c. Insulation test at [illegible] (Limit: 20 Meg Ohms min)   Record: > 550 MΩ

d. Vibration test:
   Subject the switch to vibration at [illegible] and [illegible] amplitude for 5 minutes.
   Record the setting:
   Increasing: 5.2 PSI   5.2 PSI
   Decreasing: 5.0 PSI   5.0 PSI

Check special tools: NIL

OPERATOR:

INSPECTOR:
STAMP & DATE:

CRI(E)

2nd [illegible]

HINDUSTAN AERONAUTICS LIMITED (KD)
TEST AND ACCESSORIES INSPECTION - ENGINE DIVISION
RIG TEST RECORD OF CENTRIFUGAL FUEL FILTER GNOME ENGINE

UNIT SL NO: 1132 ENG NO: [illegible] WO/P.O.R: [illegible] DATE: [illegible]

TYPE: [illegible] FUEL: [illegible] TEMP: 26° W.O. NO: [illegible]

UNIT: OVERHAUL / REPAIRED / HOURS DONE: —

SL NO	TEST		CONDITION RECORDED PARAMS			LIMIT
1	RUNNING IN		INLET PRESSURE	OUTLET PRESSURE		
	RPM	GPM				
	1500	100-140	9.5 - 10.5	—	5 MIN	[illegible]
	2000	100-140	9.5 - 10.5	—	5 MIN	
	2500	100-140	9.5 - 10.5	—	5 MIN	[illegible]
	3000	100-140	9.5 - 10.5	—	5 MIN	
	3500	100-140	9.5 - 10.5	—	5 MIN	
	4000	100-140	9.5 - 10.5	[illegible]	5 MIN	OUTLET PRS [illegible]
	4000	100-140	[illegible]		20 MIN	[illegible]
2	FINAL CALIBRATION					
	RPM	GPM				
	4000	100-140	9.5 - 10.5	[illegible]	[illegible]	10 MIN. OUTLET PRS [illegible]
	4000	100-140	100 PS	LEAK: [illegible]		5 MIN MAX LEAKS DROPS/MIN FROM SEAL DRAIN
3	AIR LEAKAGE TEST AT 15 PSI		NO LEAK			NO LEAKAGE WHEN IMMERSED IN FUEL
4	INHIBITION		Satisfactory			

OPERATOR:

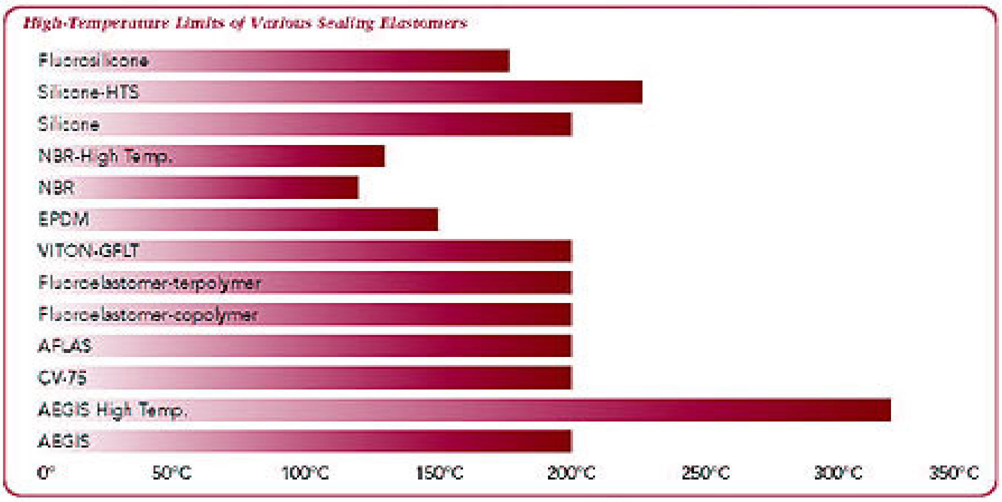
MODS FOUND EMBODIED: [illegible]

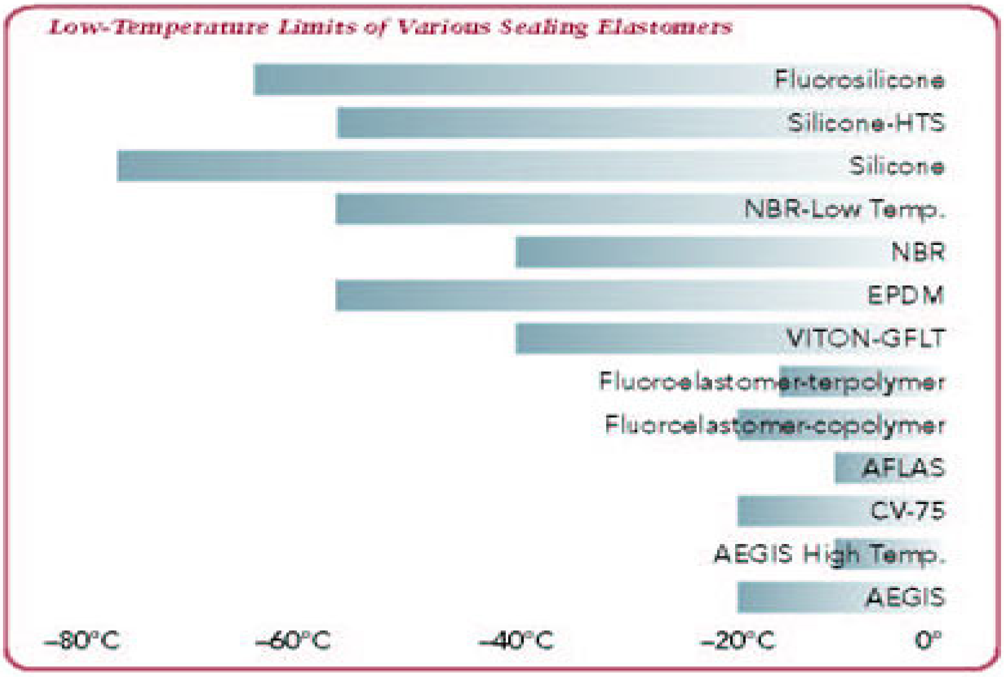
MODS EMBODIED AT HAL: NIL

INSPECTOR:
STAMP & DATE: [illegible]

REMARKS: NIL

18 ENCLOSURE V TEMPERATURE CHART FOR ELASTOMERS





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21 GLOSSARY OF TERMS

AAA	Airworthiness Approval Authority	ASSSC	Aero Stores Standardization Sub Committee
ALH	Advanced Light Helicopter (Dhruv)	ASTM	American Society for Testing and Materials
AEGIS	Trade name of Nylon resins (Company: Dupont)	AFLAS	Trade name for a type of Fluoroelastomer (Copolymer of tetrafluoroethylene and propylene)
BR	Polybutadiene rubber	BS	British Standard
BSI	British Standards Institution	CCSSC	Committee of Chairman Standardization Sub Committee
CV-75	Trade name for Fluoroelastomers (Company: Freudenberg Simrit Viton)	Ch/Ck	Cheetah/Chetak
CF	Conductive furnace (black)	CV	Continuous vulcanisation
CSM	Chlorosulphonated polyethylene	CVNR	Constant viscosity natural rubber
CR	Polychloroprene rubber	DNPT	Dinitrosopentamethylene tetramine
DBP	Dibutyl phthalate	EP	Ethylene-propylene rubber
DTD	British Defence Standard Specification	EPDM	Ethylene Propylene Diene Methylene rubber
ENB	Ethylidene - norbornene	FSi	Fluorosilicone rubber
EPC	Easy processing channel (black)		
FCM	Farrel Continuous Mixer	HM	Hindustan Material
FVSI	Trifluoropropylvinyl siloxane	IRHD	International Rubber Hardness Degree
HTS	High Temperature Silicone	ISAF	Intermediate Super Abrasion Furnace (black)
IIR	Isobutylene-isoprene(Butyl) rubber	LCA	Light Combat Aircraft
IR	Polyisoprene rubber (synthetic rubber)	LM	Low modulus (black)
ISO	International Organisation for Standardisation	Lucas	Lucas Company Specification
LTCC	Local Type Certification Committee	MIL	Federal American Specification

LS	Low Structure (Black)	MRFB	Malayan Rubber Fund Board
MB	Masterbatch	Natsyn	Goodyear's trademark for a series of solution polymerized high cis- polyisoprene
MK I / MK IA	Mark I/ Mark Indian Airforce	NFL	French Specification
MSRR	Material Specification Rolls Royce	NS	Non-staining (black)
NBR	Acrylonitrile-butadiene copolymer(Nitrile) rubber	p.p.m.	parts per million
NIPOL	Chemical trade name for Isoprene rubber of M/s NIPPON ZEON Co. Ltd., Japan	PTFE	Polytetrafluoroethylene
p.p.h.r.	parts per hundred parts of rubber	SI	Dimethyl siloxane
PVSI	Phenyl Methyl Vinyl Siloxane	VSI	Methyl Vinyl Siloxane
RSS	Ribbed Smoked Sheet	Viton	Trade name of Fluorocarbon rubber
SMR	Standard Malaysian Rubber	Viton-GFLT	Trade name for Fluorocarbon (For High heat and Superior chemical resistance)

TERMS	DEFINITIONS
Antiozonant	Compounding ingredient used to retard deterioration caused by ozone.
Antioxidant	Compounding ingredient used to retard deterioration caused by oxidation
Banbury mixer	A specific type of internal mixer.
Batch	Product of one mixing operation in an intermittent process.
Blister	A raised spot on the surface or a separation between layers usually forming a void or air filled space in the vulcanised article.
Bloom	A discoloration or change in appearance of the surface of a rubber product caused by the migration of a liquid or solid to the surface, e.g. sulphur bloom, wax bloom. Not to be confused with dust on the surface from external sources.
Calender	Machine with two or more rolls for converting rubber, or a combination of rubber with other materials, into sheet of a controlled thickness
Composition	Kinds and proportions of all ingredients contained in a mix.
Compound(mix)	Intimate mixture of a polymer(s) with all the ingredients necessary for the

	finished article.
Extruder	Machine for extrusion, generally with a driven screw, for continuous forming of rubber or plastic through a die.
Grain	Directional orientation of rubber or filler particles resulting in anisotropy of material.
Mastication	Process of plasticising raw rubber irreversibly by the combined action of mechanical work, frequently at elevated temperature.
Masterbatch	Homogenous mixture of rubber and one or more compounding ingredients in known proportions for use as a raw material in the preparation of the final mix
Mill	Machine with two driven rolls forming a nip for masticating, plasticizing, mixing or sheeting.
Mooney viscometer	Measure of the viscosity of a raw or unvulcanised rubber or rubber mix, determined in Mooney shearing disc viscometer
Nip	Line of surface contact between two rolls, or the gap between them in the plane of their axes.
Rheometer (Monsanto)	One type of curemeter. It is in worldwide use and has many applications as a process control instrument in addition to its normally accepted laboratory use as a measure of stiffness, scorch and functional modulus characteristics of a rubber compound. In certain cases it is even used indirectly as a comparison of dispersion by examining the reproducibility of several batches of the same material.
Scorch	Premature vulcanisation of a rubber mix.
Vulcanisation	Normally irreversible process, in which rubber, through a change in its chemical structure, usually brought about by crosslinking, is converted to a condition in which the elastic properties are conferred, re-established, improved or extended over a greater range of temperature.