Chapter 5 Seal Material

5.1 Rubber

1.Rubber Material Symbol

<Table 1> ASTM rubber classification that used by NAK.

Symbol	Abbreviation	Name	ASTM Classification
B	SBR	Styrene butadiene rubber	AA
C	CR	Chloroprene rubber	BC, BE
E	EPDM	Ethylene propylene rubber	BA, CA, DA
F	FVMQ	Fluorinated silicone rubber	FK
G	CSM	Chlorosulfonated polyethylene	CE
H	HNBR	Hydrogenated NBR rubber	DH
M	AEM	Ethylene/Acrylic rubber	EE, EF, EG
N	NBR	Acrylonitrile butadiene rubber	BF, BG, BK, CH
P	ACM	Polyacrylate rubber	DF, DH
R	NR	Natural rubber	AA
S	VMQ	Silicone rubber	FC, FE, GE
T	PTFE	Polytetrafluoro ethylene	
U	PU	Urethane rubber	BG
V	FKM	Fluorocarbon rubber	HK
X	XNBR	Carboxylated NBR	BF, BG, CH
Z		Other	

2.Rubber types and general property

<Table 2>Rubber types and their properties

Item / Type	Temp. Range (℃) High Temp.	Temp. Range (℃) Low Temp.		Property
NBR				Good resistance to alcohol, amines, petroleum oils, and gasoline's over a wide range of temperatures. Also good resistance to caustic salts. Fair acid resistance. Poor in strong oxidizing agents, chlorinated hydrocarbons, ketones, and esters.
	100	**-55**	***Low ACN***	Increase low temperature resistance and elastic property. Used in where low temperature property is more important than oil resistance property.
	100	**-40**	***Mid ACN***	The property is between low and high ACN content. Used in low aromatic content or in where a little swell is acceptable.
	100	**-25**	***High ACN***	Increase oil resistance、heat resistance、tensile strength、Hardness, abrasion resistance is improved, also increase gas impermeability；usually used in where high oil resistance is required, such as oil well、fuel battery cap、fuel hose, and other place where aromatic fuel、oil and solvent.
HNBR				HNBR is made from NBR by hydrogenation, it has high temperature resistance, abrasion resistance and good physical properties.
	125	**-40**	***Sulfur Cure***	Better heat resistance and oil resistance than NBR (if containing heavy metal salt, rubber color will be affected).
	150	**-40**	***Peroxide Cure***	The Peroxide cured HNBR suits more widely temperature range, better antioxidant and would not affect color.
ACM	**150**	**-10**		Widely used in diaphragm, hose for automotive application. Good resistance to heat, ozone and oil. Generally attacked by water, alcohol, glycol and aromatic hydrocarbons. The molecular structure contains ethyl acrylate(EA)、butyl acrylate(BA) and methoxy ethyl acrylate(MEA). More BA content get more low temperature resistance, more MEA content get more oil resistance.
VMQ	**225**	**-55**		The most widely temperature ranges for application. Good weather and ozone resistance. But poor mechanical property and poor chemical resistance.

FKM			Excellent chemical resistance but ester and ketone. The cost is high.	
	250	**-25**	***Dipolymer***	Copolymer of vinylidiene fluoride and hexafluoro propylene, 66% fluorine content。
		-20	***Tripolymer***	Copolymer of vinylidiene fluoride, hexafluoro propylene and tetrafluro ethylene, 68% fluorine content, more fluid resistance than dipolymer.
EPDM	**150**	**-55**	Stable in polar fluids(alcohol, ketone and glycol), and hydrochloric acid. Due to the low specific gravity, it can compound to high filler content.	
SBR	**100**	**-40**	Could mixed with NR and other synthetic rubber. Poor mechanical property and low cure speed, low elasticity, high heat build-up.	
PTFE	**250**	**-50**	Due to the low friction coefficient, it is used in oil seal lip. Poor elastic property.	
CR	**100**	**-40**	Good in moderate acid, alkali and salt solutions. Resistant to commercial oils and fuels. Poor in chromic and nitric acids, aromatics and chlorinated hydrocarbons.	

3.Basic Requirements for Classification for ASTM D2000

When selecting elastomer seals for specific applications, the American Society fot Testing and Materials (ASTM) is an important reference.

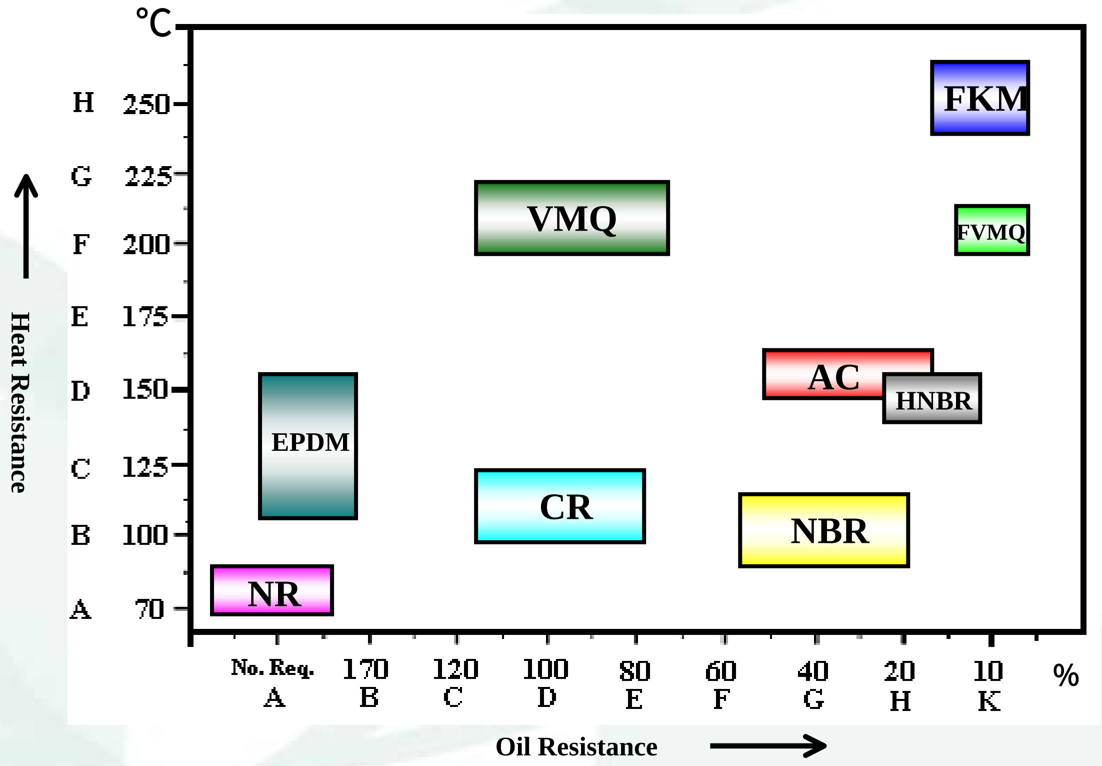
<Table.3>ASTM D2000 Rubber Test Condition

	ASTM D2000 Type	BF , BG BK , CH	BE , BC	DF, DH	FC, FE GE	FK	HK
	Rubber Material	NBR	CR	ACM	VMQ	FVMQ	FKM
Basic Property	Hardness(shore A)	70 ± 5	70 ± 5	70 ± 5	70 ± 5	60 ± 5	70 ± 5
	Tensile Strength(psi)	2000↑	2000↑	1000↑	870↑	870↑	1450↑
	Elongation(%)	250↑	250↑	200↑	150↑	150↑	175↑
Heat Aging Test	Temp.(°C)/Time(hr)	100 / 70	100 / 70	150 / 70	225 / 70	225 / 70	250 / 70
	Hs Change(max,%)	± 15	+15	+10	+10	+15	+10
	Tb Change(max,%)	± 30	-15	-25	-25	-45	-25

	Eb Change(max,%)	-50	-40	-30	-30	-45	-25
Compression Set	Temp.(°C)/Time(hr)	100 / 22	100 / 22	150 / 22	175 / 22	175 / 22	175 / 22
	Compression Set (max,%)	25	35	40	30	45	30
Lubricating oil / Fuel oil Resistance	Temp.(°C)/Time(hr)	100 / 70	100 / 70	150 / 70	150 / 70	23 / 70	23 / 70
	Oil/Solvent	ASTM No.1 Oil	ASTM No.1 Oil	ASTM No.1 Oil	ASTM No.1 Oil	Fuel C	Fuel C
	Hs Change(max,%)	-5 to +10	± 10	-5 to +10	0 to -15	0 to -15	± 5
	Tb Change(max,%)	-25	-30	-20	-20	-60	-25
	Eb Change(max,%)	-45	-30	-30	-20	-50	-20
	Volume Change (max,%)	-10 to +5	-10 to +15	± 5	0 to +15	0 to +25	0 to +10
	Temp.(°C)/Time(hr)	100 / 70	100 / 70	150 / 70	150 / 70	150 / 70	
	Oil/Solvent	IRM 903 Oil	IRM 903 Oil	IRM 903 Oil	IRM 903 Oil	IRM 903 Oil	
	Hs Change(max,%)	-10 to +5	-20	-15	-40	0 to –10	
	Tb Change(max,%)	-45	-45	-40	—	-35	—
	Eb Change(max,%)	-45	-30	-40	—	-30	
	Volume Change (max,%)	0 to +25	+80	+25	+60	0 to +10	
Low Temperature Brittleness Test	Temp.(°C)/Time(hr)	-40 / 3	-40 / 3	-10 / 3	-55 / 3	-55 / 3	-18 / 3
	No brittle	PASS	PASS	PASS	PASS	PASS	PASS

4.Material application temperature range

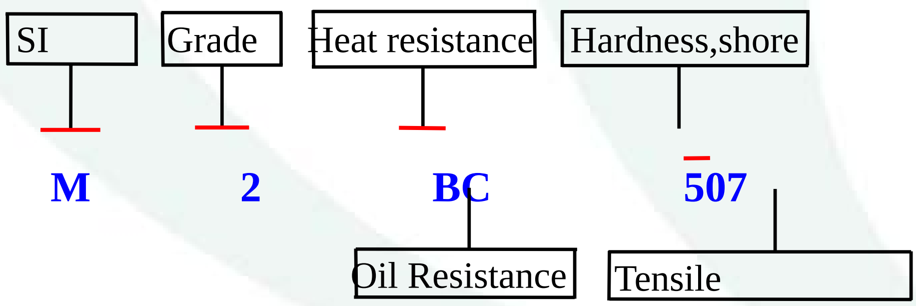
<Table 4>Rubber Material application temperature range



5.ASTM D2000 Line Call-Outs

A “line call-out”, which is a specification, shall contain: the documents names, the prefix letter M, The grade number, the material designation (type and class), and the hardness and tensile strength, follow by the appropriate suffix requirements. Following is an example of a “line call-out” or specification:

<Table 5>An example of a specification



6.Typical Properties of Selected Elastomer

<Table 6> The Typical Properties of Selected Elastomer

Rubber Material	NBR	CR	EPDM	ACM	VMQ	FVMQ	FKM
Tear Strength	○	⊙-○	⊙	△-⊙	△-⊙	△	⊙-○
Abrasion Resistance	◎	◎	○	⊙	△-⊙	△	○
Compression Set	○-◎	○-◎	○-◎	○	⊙-◎	○	○-◎
Resilience 23°C	○	○-◎	○	⊙	△-◎	⊙	⊙
Fire resistance	△	○-◎	△	△	⊙-◎	◎	◎
Weather resistance	△	◎	◎	◎	◎	◎	◎
Water Resistance	◎	○	◎	△	○-◎	◎	◎
Steam Resistance	⊙-○	⊙	○-◎	x	⊙-○	⊙-○	○
Ozone Resistance	△-⊙	◎	◎	◎	◎	◎	◎
Oxygen resistance	○	◎	◎	○	◎	◎	◎
Acid Resistance (Dilute)	○	◎	◎	△-⊙	○	◎	◎
Acid Resistance (Concentrate)	○	◎	◎	△-⊙	⊙	○	◎
Base Resistance (Dilute)	○	◎	◎	△-⊙	◎	◎	◎
Base Resistance (Concentrate)	○	◎	◎	△-⊙	◎	○	x
Synthetic Lubricant	○-◎	△	x	△	x	◎	◎
Low Polar Lubricant	◎	◎	x	◎	○	◎	◎
High Polar Lubricant	◎	○	x	◎	⊙	◎	◎
Animal、Vegetable Oil	○	○	○-◎	○	◎	◎	◎
Gas	○-◎	○	⊙	○	△	△	◎

impermeability							
Electricity resistance	△-⊙	◎	◎	⊙	○-◎	◎	○
Metal Adhesion	○-◎	○-◎	⊙-○	○	○	⊙	⊙
◎：Excellent ○：Good ⊙：Fair △：Poor X：Very Poor							

7.The Stability of Rubber in Chemicals, Oils, and Fluids

<Table 7>Rubber Chemical Resistance Guide

	Fluid	HNBR	NBR	EPDM	CR	CSM	VMQ	FKM	ACM
	Steam(150℃)	○	X	◎	X	X	X	△	X
Organic Acid	Acetic Acid	○	○	◎	◎	◎	◎	○	X
Inorganic Acid	hydrochloric acid (25%)	○	○	◎	◎	◎	◎	○	X
	Phosphoric Acid (20%)	◎	○	◎	○	◎	○	◎	—
	Nitric Acid(25%)	○	X	○	◎	◎	○	△	X
Base	Sodium Hydroxide (30%)	◎	○	◎	X	◎	○	○	—
	氨水(28%)	◎	◎	◎	◎	◎	◎	○	X
Salt Solution	NaCl (30%)	◎	◎	◎	◎	◎	◎	◎	—
	Na_2CO_3 (10%)	◎	◎	◎	◎	◎	◎	○	—
Oxidizing Agent	Hydrogen Peroxide (3%)	○	△	○	△	◎	◎	◎	—
	Sodium Chloride(5%)	○	X	○	X	○	○	◎	X
Parafinc Fluid	Isooctane	◎	◎	X	○	○	X	◎	◎
Aromatic Fluid	Benzene	△	△	X	X	X	△	◎	X
Chlorinated Fluid	Trichloroethylene	△	△	X	X	X	X	◎	—
Alcohol	Methanol	◎	◎	◎	◎	◎	◎	△	X
	Ethanol	◎	◎	◎	◎	◎	◎	◎	X
Ether	Ethyl Ether	△	△	△	X	X	X	X	X

Ester	Ethyl Ester	X	X	○	△	△	X	△	—
Ketone	Methyl Ethyl Ketone	X	X	◎	X	X	X	X	X
Aldehyde	Furfural	○	△	◎	X	X	X	X	X
Amine	Trihydroxyethylamine	◎	△	◎	◎	◎	X	X	X
	Carbon Disulfide	△	△	X	X	X	—	◎	—

◎:Excellent ○:**Good** △:**Fair** X:**Poor**

<Table 8> Oil and Fluid Resistance of Rubber

Rubber / Oil,Chemical		HNBR	NBR	EPDM	SBR	PTFE	VMQ	FKM	ACM
Engine oil	SAE #30	◎	◎	X	X	◎	◎	◎	◎
	SAE 10W-#30	◎	◎	X	X	◎	○	◎	◎
Gear oil	Vehicles used	◎	◎	X	X	◎	△	○	◎
	Industrial synthetic base	◎	◎	△	△	◎	△	○	△
Auto transmission Fluid		◎	◎	X	X	◎	X	○	◎
Brake Fluid	DOT 3 (Glycol)	X	△	○	○	◎	○	X	X
	DOT 5 (Glycol)	X	△	○	○	◎	○	X	X
	DOT 5 (silicone base)	◎	◎	X	○	◎	X	○	○
Turbine oil		○	○	X	X	◎	△	◎	◎
Mechanical oil(No.2 lubrication oil)		○	○	X	X	◎	X	◎	○
Hydraulic oil(mineral oil)		◎	◎	X	X	◎	△	◎	◎
Antiburn oil	Phosphoric ester	X	X	X	X	◎	◎	△	X

	Water + ethylene glycol	○	○	X	X	◎	△	△	X
Cutting oil		◎	◎	X	X	◎	◎	◎	△
Grease	Mineral	◎	◎	X	X	◎	◎	◎	◎
	Silicone	◎	◎	X	○	◎	X	◎	◎
	Fluoro	◎	◎	X	X	◎	◎	X	◎
Cooling media	R12+paraffinic	◎	○	X	X	◎	X	X	X
	R134a+glycol	○	△	◎	X	◎	X	X	X
Gasoline		○	△	X	X	◎	X	◎	X
Naphtha		○	△	X	X	◎	X	◎	X
Heavy oil		◎	○	X	X	◎	X	◎	△
Antifreeze fluid(ethylene glycol)		○	○	◎	◎	◎	△	X	X
Warm water		◎	○	◎	◎	◎	○	○	X
Salt water		◎	○	◎	◎	◎	X	○	X
Steam		○	X	○	△	◎	X	X	X
Hydrochloric acid 10%		○	○	◎	○	◎	○	○	○
Sulfuric acid 30%		△	△	○	△	◎	X	△	△
Nitric acid 10%		△	X	○	X	◎	X	△	X
Sodium hydroxide 40%		◎	○	◎	◎	◎	X	X	X
Benzene		X	X	X	X	◎	X	X	X
Alcohol		○	○	◎	◎	◎	○	○	X
Acetone		X	X	X	X	◎	△	X	X

◎:Excellent ○:Fair △: Poor X:Failure

8.Rubber Application Temperature Range for Several Oils

<Table. 9>Temperature Range of Rubber For Various Oil

Oil	Continuous Test Temperature Renge	Cycle Test Temperature Range	Engine Oil	Gear Oil	Transmission Oil	General Hydraulic Oil	Mineral Grease	Silicone Grease	Diesel Engine Oil	Gasoline /Engine Fuel (Standard)	Gasoline /Engine Fuel (Super)
Temperature Range (°C)			+150 ~ -40	+150 ~ -40	+160 ~ -50	+100 ~ -30	+100 ~ -30	+250 ~ -50			
Material											
NBR	+100 ~ -30	+120 ~ -30	100	90	100	100	100	100	＊	＊	＊
FKM	+200 ~ -20	+250 ~ -20	150	150	160	100	100	200	150	150	150
EPDM	+120 ~ -50	+150 ~ -50	NS	NS	NS	NS	NS	120	NS	NS	NS
VMQ	+200 ~ -55	+225 ~ -55	130	＊	＊	＊	100	＊	NS	NS	NS
HNBR	+130 ~ -30	+150 ~ -30	130	110	130	100	100	130	＊	＊	＊
IIR	+120 ~ -40	+140 ~ -40	NS	NS	NS	NS	NS	120	NS	NS	NS
AU Polyester PU	+80 ~ -30	+100 ~ -30	100	100	100	100	100	100	60	60	60
Polyester elastomer	+100 ~ -40	+120 ~ -40	100	100	100	100	100	100	60	60	60
PA Nylon	+100 ~ -30	+120 ~ -30	100	100	100	100	100	100	100	100	100
POM	+100 ~ -45	+120 ~ -45	100	100	100	100	100	100	100	100	100
PTFE	+200 ~ -50	+200 ~ -50	150	150	160	100	100	200	150	150	150
ACM	+130 ~ -10	+150 ~ -10	130	110	120	100	100	130	＊	＊	＊

NS: Not Suggested　＊:Not Suggested　(Unit : ℃)

9.NAK Material Code System

1st　　3rd

N　K　7　0　1

2nd　　4th & 5th

1st Digit — Material

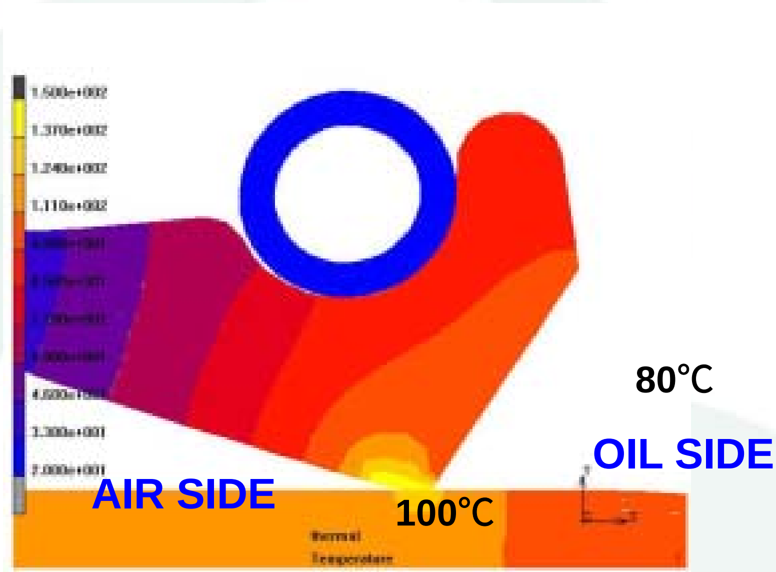
2nd Digit — Color

3rd Digit — Hardness

4th & 5th Digit — Property (Sequential Number)

1st Digit		2nd Digit		3rd Digit	
Material		Color		Hardness	
Symbol	Meaning	Symbol	Meaning	Symbol	Meaning
B	SBR	W	White	A	95
C	CR	K	Black	9	90
E	EPDM	B	Blue	B	85
F	FVMQ	R	Red	8	80
G	Hypalon	T	Gray	C	75
H	HNBR	G	Green	7	70
R	NR	N	Brown	D	65
M	VAMAC	P	Transparent	6	60
N	NBR	A	Tangerine	E	55
P	ACM	U	Purple	5	50
S	Silicone			F	45
U	PU			0	coating
V	FKM				
X	XNBR				
I	IIR				

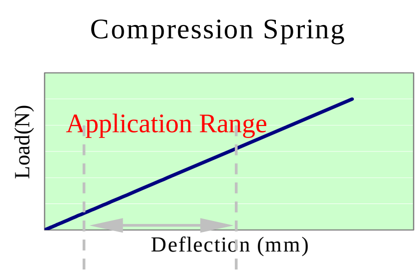
Besides considering fluid media, shaft speed, and operation temperature, we have to consider the temperature rise on the seal lip. The seal lip temperature will rise over 20℃ in normal operation <Figure 5.1>. When selecting the seal material, the heat resistance factor must be considered.

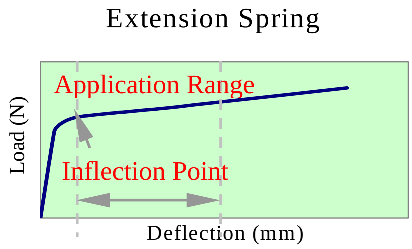


<Figure 5.1> The seal lip temperature will raise over 20℃ in normal operation

5.2 Spring

It offers radial load for sealing lip, and it also can prolong the seal life. We have to consider shaft speed, shaft run-out and anticorrosive factors to select a proper garter spring. Table 5-6 shows the spring load calculation.

		Symbol	Legend	Unit
Compression Spring	Load $P = k \cdot \delta$ Spring rate $k = \frac{Gd^4}{8D^3 N_a}$ Spring index $c = \frac{D}{d}$ 			
		P	Load	kgf
		k	Spring rate	kgf/mm
		δ	Displacement	mm
		G	Modulus	kgf/mm

Extension Spring	Load $P = k \cdot \delta + P_i$	d	Wire diameter	mm
	Initial tession $P_i = \frac{\pi d^4 G}{800D}$	D	Mean coil diameter	mm
	Spring rate $k = \frac{Gd^4}{8D^3 N_a}$	N_a	Coil number	
	Spring index $c = \frac{D}{d}$	c	Spring index	
		P_i	Initial tession	kgf

<Table 5-6> Spring load caculation

Table 5-7 shows the spring material and its application.

Fluid	**Spring Material**		
	Steel SAE 1070 SAE 1080	Stainless	
		SAE 30304	SAE30316
Oil, grease	○	○	○
Water	×	○	○
Steam	×	○	○
Salt water	×	×	○
Acid	×	×	○
Alkali	×	○	○

<Table 5-7> Spring material and its application

5.3 Case

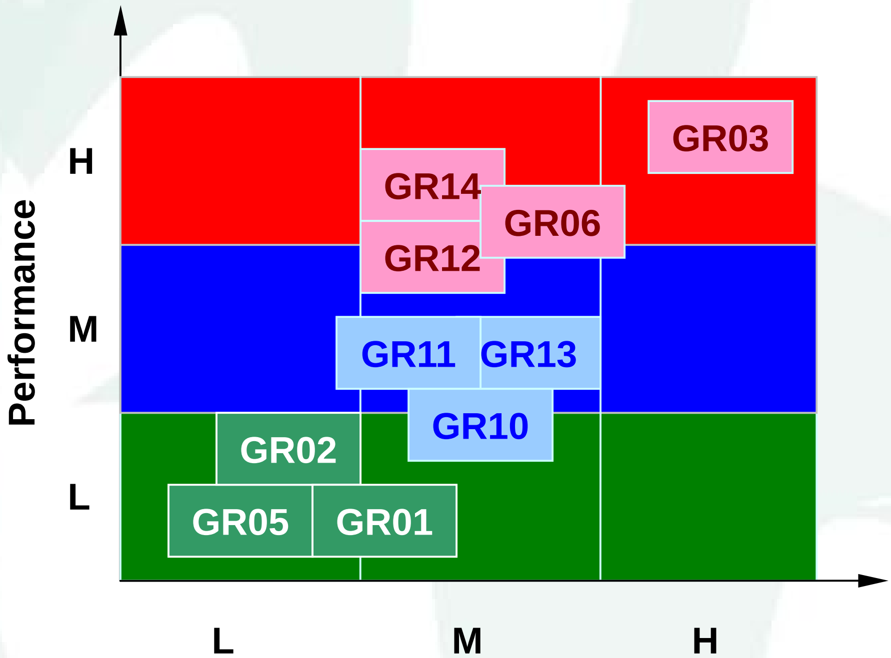
Case can improve seal stiffness and sealing function. It also helps the seal to be installed correctly. Table 5-8 shows the case material and its application.

Fluid	**Case Material**		
	Steel SAE 1008	Stainless	
		SAE 30304	SAE30316
Oil, grease	○	○	○
Water	×	○	○
Steam	×	○	○
Salt water	×	×	○
Acid	×	×	○
Alkali	×	○	○

<Table 5-8> Case material and its application

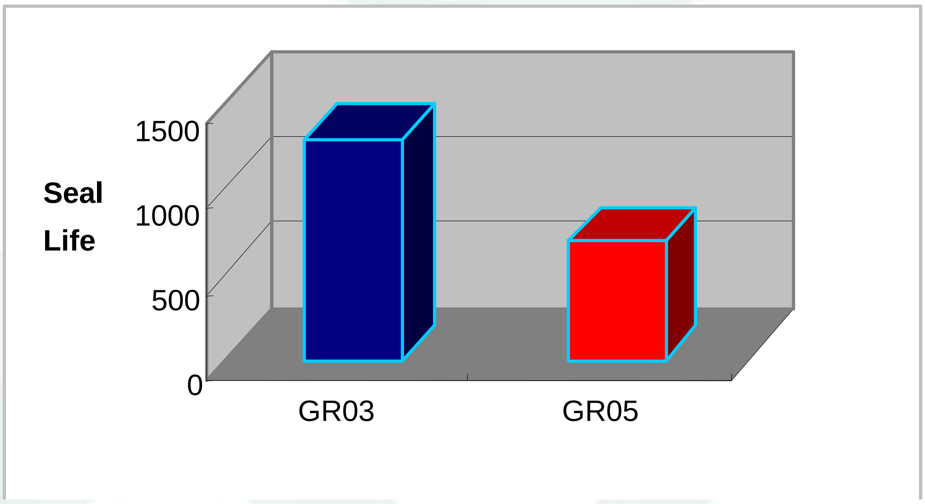
5.4 Grease

Grease has the high adhesive property, and it is used in the machinery that doesn't need to supply lubrication oil constantly. It is under semi-solid status that has good lubrication function, and it also have a good function for preventing dust or other contaminant. Figure 5-2 shows the performance for various greases



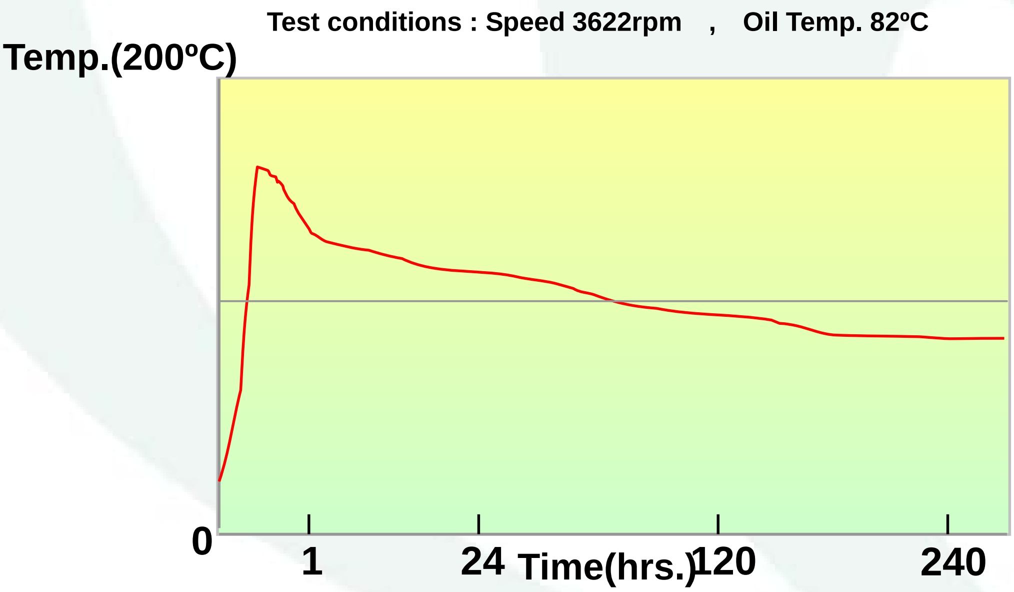
<Figure 5-2> Performance and price for various greases

We can find that different greases have a great influence on seal life. <Figure 5-3>



<Figure 5-3> Different greases have a great influence on seal life.

The grease will carbonize under high temperature. The high speed motion will make the temperature rise greatly inside the seal. When selecting the seal material, the heat resistance factor must be considered. <Figure 5-4> shows the grease temperature raise inside the AP seal.



<Figure 5-4> Grease temperature raise inside the AP seal.